JOURNAL OF AGRICULTURAL RESEARCH

VOL. 37. WASHINGTON, D. C. JULY 15, 1928, NO. 2

THE WATER RELATIONS OF YAKIMA VALLEY SOIL [1]

By CARL S. SCOFIELD, *Senior Agriculturist in Charge*, and COULSEN C. WRIGHT, *Assistant Agronomist, Office of Western Irrigation Agriculture, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

There are strong economic reasons why in the Yakima Valley, Wash., as in many other irrigated sections, the most efficient use should be made of the available supply of irrigation water. The area of land available for irrigation is somewhat larger than can be irrigated adequately with the present water supply, and the local topography makes it necessary to lift some of the water to certain areas of the irrigable land.

The quantity of dissolved salts in the water supply of the Yakima Valley is less than 100 parts per million, and the proportion of alkaline-earth bases (calcium and magnesium) to alkaline bases (sodium and potassium) is high. There are a few areas in the valley where the subsoil is saturated with water and where the salt content of the soil solution is so high as to be troublesome. These water-logged or salty areas, which need drainage, are mostly confined to the lower lands. The higher bench lands generally have good subsoil drainage and appear to be in little danger of impaired productivity from the accumulation of subsoil water or salt.

The immediate practical problem of the irrigator in the Yakima Valley is how to make the most efficient use of the irrigation water that reaches his farm. This involves chiefly the proper leveling of the land to obtain uniform distribution of the water and the avoidance of the waste of water either by surface run-off or by percolation below the root zone. The losses from surface run-off can readily be seen, but those from percolation are not visible and can be detected only by subsoil exploration, which requires much labor and the use of equipment for determining soil moisture.

The chief purpose of the investigations reported in this paper was to bring together some of the simpler facts concerning the water-holding capacity of the type of soil that occurs on the higher lands of the Yakima Valley. Such information should be useful not only to the irrigators of that region but also to those of other regions. Irrigators generally need more precise information about the water relations of the soil. The soil acts as a reservoir in which to store water for the use of crop plants. The effective capacity of this reservoir is limited by the quantity of water the soil can hold against the force of gravity, by the quantity of water it can withhold from absorption by the plant roots, and by the depth of the root zone.

By a series of investigations such as here reported it is possible to estimate the quantity of water that can be stored in each successive

[1] Received for publication May 17, 1928; issued October, 1928.

layer of the root zone of an irrigated soil and the quantity that is withheld by the soil from plant absorption. The actual depth of the root zone is not the same for different soils or different crops. It is often limited by the depth to which irrigation water penetrates, though in some situations it is limited by the occurrence of a saturated zone in the subsoil. When the irrigator knows approximately how much water can be stored in the soil for a given depth of root zone he can estimate the quantity of water that will be required to penetrate to the desired depth.

These investigations were conducted at the irrigation branch station of the Washington State Agricultural Experiment Station,[2] near Prosser, Wash., on one of the areas to which water must be lifted by pumping. The present annual allotment of water for this area is 3 acre-feet per acre. This water is distributed to the fields by the "corrugation" method of irrigation, which is commonly used throughout the Yakima Valley. The water is conducted across the field in small furrows, and where the surface slope is slight or the soil is highly permeable there is some danger that the irrigation water may penetrate below the root zone at the upper end of the field before the lower end of the field has been irrigated sufficiently.

THE WATER RELATIONS OF THE SOIL

The soil of the Prosser experiment farm is classed as a fine sandy loam and is known locally as volcanic ash. It is of a type that is common throughout the Yakima Valley and the Columbia Basin. It contains very little clay and takes water readily. The only impediment to the rapid percolation of water through the root zone is the occurrence in spots of 1 to 2 inch layers of very fine silt having a compact and laminated structure. These layers may occur at any depth in the root zone or below it. When very compact, as they sometimes are, they retard the percolation of water temporarily. Their occurrence is one of the causes for the differences in moisture content found in duplicate samples taken from the same plot. This fine silt holds more water than the coarser soil and thus causes aberrant results for moisture determinations.

The general moisture relations of the soil may be indicated by reference to the so-called moisture equivalent. This term may be defined as the quantity of water, expressed as a percentage of the dry weight of the soil, that is held by the soil against a centrifugal force one thousand times the force of gravity.[3] In order to afford a basis of comparison to the other soils of which the moisture equivalent is known, samples of the Prosser soil were submitted to J. W. McLane, of the Bureau of Plant Industry, for the determination of their moisture equivalents. These samples were taken to represent each foot in depth to 6 feet. Twelve samples were taken for each section, and these were thoroughly mixed to make a composite for each foot. The results of the moisture-equivalent determinations are shown in Table 1. In converting the figures for percentage of moisture into those for inches of water it is assumed that the dry

[2] In this paper this station is called the Prosser experiment farm. Certain features of the investigational work at this station are conducted cooperatively by the Washington State College and the Office of Western Irrigation Agriculture of the Bureau of Plant Industry, U. S. Department of Agriculture. C. C. Wright is detailed from the Office of Western Irrigation Agriculture to conduct these cooperative investigations, of which the subject of the present paper constitutes a part.

[3] BRIGGS, L. J., and MCLANE, J. W. THE MOISTURE EQUIVALENTS OF SOILS. U. S. Dept. Agr., Bur. Soils Bul. 45, 23 p., illus. 1907.

soil as it occurs in the field weighs 86 pounds per cubic foot. The method of conversion is to divide the percentage of moisture by 6.0465. The figure for density was adopted after making a number of tests throughout the 6-foot profile, using three different methods of sampling. These tests indicated that the soil of the lower sections is more compact than that near the surface, but it is believed that 86 pounds per cubic foot is not far from the average weight of the soil of these plots.

TABLE 1.—*Moisture content of the soil profile through the root zone in field E-5, Prosser experiment farm*

Depth of sampling	Moisture equivalent: Percentage of dry weight of soil	Moisture equivalent: Inches of water per foot of soil	Wilting point of alfalfa in inches of water per foot of soil	Field-carrying capacity in inches of water per foot of soil	Field-carrying capacity less wilting-point content
Feet					*Inches*
1	16.2	2.68	0.051	3.06	2.55
2	16.2	2.68	.81	3.55	2.74
3	14.2	2.35	.77	3.32	2.55
4	13.3	2.20	.74	2.79	2.05
5	14.3	2.36	1.01	2.78	1.77
6	17.0	2.81	1.02	2.92	1.90

In any attempt to estimate the quantity of water that may be held in the soil of the root zone available for the use of crop plants it is necessary to establish the point of moisture condition that represents the minimum below which the plants are not able to absorb the water they need for normal growth. This point is commonly referred to as the wilting point. Briggs and Shantz [4] have expressed these relationships as follows:

$$\frac{\text{Moisture equivalent}}{1.84 \pm 0.013} = \text{wilting coefficient.}$$

In the investigations reported here the wilting point of the soil was determined by the direct method rather than by computing it from the moisture-equivalent determinations. The method used was to take samples of soil in 1-foot sections to the depth of 6 feet in several alfalfa fields (two locations in field E-5) on the Prosser experiment farm at a time when the alfalfa plants were so severely wilted that they did not recover their normal turgidity at night. These moisture determinations were made in duplicate for each field. The results, expressed as inches of water per foot of soil, are shown in Table 2. When these results are compared with figures for moisture equivalent, given in Table 1, it can be seen that the difference between the moisture equivalent and the wilting point is greater than would be obtained by computation, using the factor proposed by Briggs and Shantz. The figures in the last two columns of Table 2 are believed to represent conditions in soils that are very similar to the samples on which the moisture-equivalent determinations were made as reported in Table 1; consequently the figures in these two columns have been averaged to obtain wilting-point figures for soil of that type. These averages are given in column 4 of Table 1.

[4] BRIGGS, L. J., and SHANTZ, H. L. THE WILTING COEFFICIENT FOR DIFFERENT PLANTS AND ITS

TABLE 2.—*Water content of soil on the Prosser experiment farm at the wilting point for alfalfa*

Depth of sampling	Inches of water per foot of soil in—				
	Field A-4	Field B-4	Field E-4	Field E-5 (1)	Field E-5 (2)
Feet					
1	0.69	0.62	0.64	0.50	0.52
2	.78	.78	.78	.86	.76
3	.78	.78	.72	.68	.87
4	.78	.73	.80	.61	.88
5	.78	.73	.78	.77	1.25
6	.78	.62	1.81	.68	1.36
Average [a]	0.76	0.71	0.92	0.68	0.94

[a] Average per foot of first 4 feet = 0.72, average per foot of all 6 feet = 0.80.

Another essential point to establish in the water relations of the soil is the field-carrying capacity. This may be defined as the quantity of water the soil will hold against gravity. It is significant as indicating the intimate relations that exist between the soil and its suspended solution that the quantity of water so held against the normal pull of gravity is not very much greater than the quantity held against a force one thousand times that of gravity as represented by the moisture equivalent. For the soil represented by the samples reported in Table 1 the field-carrying capacity was determined by taking samples in 1-foot sections to the depth of 6 feet from plots that had recently been heavily irrigated. The field-carrying capacities of Table 1 are based on duplicate samples, separately determined, from each of three plots that had been irrigated about 24 hours before the samples were taken. The quantities of irrigation water applied were, respectively, 11.5, 12, and 18 inches. At the time the irrigation water was put on, the soil was already in a fairly moist condition, so that as a result of irrigation the percolating water passed below the sixth foot.

An estimate of the quantity of water that may be held available for crop plants in the root zone of this soil to the depth of 6 feet may be made by taking the difference between the quantity of water found shortly after irrigation, as shown in column 5 of Table 1 and the quantity found at the time when alfalfa was permanently wilted, as shown in column 4 of that table. These differences, which for each foot are shown in column 6 of the table, and which may be regarded as the capacity of this soil for holding available water, average nearly 2.5 inches per foot for the upper 4 feet and total about 13.5 inches for the 6-foot section. It seems probable that the quantity of water found in the fifth and sixth feet under the wilted alfalfa is rather larger than would be found at the true wilting point for that type of soil. This may have been due to the presence of some fine silt in those sections, or more probably to the fact that the roots of the alfalfa plants were not so abundantly distributed at that depth. On the other hand, the smaller quantity of water found in the first foot was probably due partly to the effect of surface-evaporation losses rather than wholly to the absorption of the alfalfa roots.

A survey of all the results available from soil-moisture determinations made at the Prosser experiment farm leads to the conclusion

that in this soil crop plants are not able to withdraw the water to a point much below 0.75 inch per foot, and that probably for the best cropping results irrigation water should be applied when the water content in the zone of active root absorption is not lower than 1 inch per foot. Furthermore, it is apparent that when the soil is dry enough to require irrigation it is possible to store about 2 inches of available water per foot of soil in that root zone.

THE FIELD PLOTS AND THE MEASUREMENT OF THE WATER

The plots used for the studies of water relations were located in field E–5 of the Prosser experiment farm. Each plot was 30 feet square and was surrounded by a dike about 12 inches high. The surface of each plot was carefully leveled to promote the uniform penetration of the irrigation water. These plots or basins, of which there were six, were arranged in a single series. The irrigation water was applied through a wooden flume laid along one side of the series of basins. During the first year of the experiment, 1924, the water was measured over a Cipoletti weir. In 1925 and 1926 a submerged orifice irrigation meter was used. The measuring device was installed in a box set in a branch from a head ditch near the upper end of the series of basins. The volume of water flowing through the weir or meter was regulated to a small but constant stream by means of a turnout gate in the head ditch. Only one basin was watered at a time, and after one basin was irrigated the water was wasted down the flume while the discharge reading was being checked and the figures recorded. It is believed that the arrangement was such that a high degree of accuracy was obtained in the water measurements.

The soil samples for moisture determination were made by taking two cores from each plot with a soil tube. The cores for each foot section were collected in separate soil cans and dried separately, so that each figure for soil moisture is the mean of two determinations. The method of converting the percentages of moisture into inches of water has already been explained.

The data accumulated during the three irrigation seasons 1924 to 1926 afford an opportunity to test the reliability of the methods of measurement and of conversion used in this series of experiments. Fifty-four sets of measurements were made, each involving the quantity of water applied to the soil and the increase in moisture content resulting therefrom. Of these there were 18 cases in which the quantity of water added, together with the quantity already present in the 6-foot section, gave a total of more than 16 inches of water for that section, and consequently it is assumed that some loss occurred through percolation. These cases include the four heaviest applications of the second irrigation in 1924 and the seven 5-inch irrigations of 1925 and 1926.

There remain, then, 36 cases where there is reason to believe that there was little if any percolation loss from the root zone immediately following irrigation, even though the quantity of water in the 6-foot section was in a few instances above 16 inches. For each of these cases there are available the figures for (1) the quantity of water present before irrigation, (2) the quantity of water applied, and (3) the quantity of water present after irrigation. If there were no error either in the measurement of the water applied or in the

determination of the water in the soil before and after irrigation, there would be no difference between the two results except for the loss by evaporation during the 24 hours between irrigation and the second sampling of the soil. As a matter of fact, in 24 of the 36 cases the increase in water content reported from the soil samples is less than the estimate as to the quantity of water applied. In 12 cases the quantity reported from the soil samples was larger. The average difference for all cases is −0.16 inch; that is to say, the average increase in soil moisture in the root zone to the depth of 6 feet was 0.16 inch less than the quantity of water applied as irrigation.

RESULTS OF THE INVESTIGATIONS

THE FIRST IRRIGATION OF 1924

The land on which the six basins were located had not previously been irrigated, although water had been used on near-by fields. The basins were prepared in the early summer of 1924, and on July 7 of that year samples were taken from each plot to the depth of 4 feet for moisture determinations. The results of these tests, two sets of samples from each plot, are given in Table 3. It will be seen from this table that the moisture content of the first foot was well below what is regarded as the wilting point for that soil; that of the second foot was approximately the same as the wilting point; and those of the third and fourth feet were above that point. Conditions were very similar in all six plots. The season had been a dry one even for that climate. The precipitation for the three months, April, May, and June, had been only 0.14 inch, while the evaporation from a free-water surface for the same period had been 16.93 inches.

TABLE 3.—*Moisture content of the soil of six plots in field E-5, Prosser experiment farm, July 7, 1924, one day before irrigation*

Plot	Inches of water per foot of soil at depth of—				
	1 foot	2 feet	3 feet	4 feet	Total moisture to 4-foot depth
A	0.75	0.77	0.89	0.99	3.40
B	.55	.90	.93	1.06	3.44
C	.57	.95	.97	1.53	4.02
D	.39	.69	1.01	1.34	3.43
E	.21	.55	.90	1.03	2.69
F	.29	.85	1.04	1.13	3.31
Average	.46	.78	.96	1.18	3.38

On July 8 all six plots were irrigated. The quantity of water applied was estimated as equivalent to 4.5 inches in depth for the areas within the borders. On the following day soil samples were taken in duplicate from each plot for moisture determinations. The results of these are given in Table 4. In comparing the two tables that show the moisture conditions in these plots the day before and the day after irrigation it may be noted that the average increase in moisture content was 4.12 inches from an irrigation of 4.5 inches. In view of the magnitude of the errors of sampling and of water measurement these results are fairly close. Furthermore, there was probably

some loss from evaporation in the 24 hours following irrigation and some additional loss from the absorption of water by the dikes surrounding the small plots. With respect to the individual plots, the increase in moisture content ranged from 3.56 to 4.43 inches. The increase in the first foot of soil averaged 2.43 inches and that in the second foot 1.45 inches, leaving only 0.24 inch to pass to the lower levels. In this dry soil, then, the absorptive capacity was approximately 2 inches for each foot. This figure is lower than is given in the last column of Table 1 as the difference between the field-carrying capacity and the moisture content at the wilting point for this type of soil. The differences may be due in part to very local differences in the soil texture and in part to differences in structure, such as might develop after repeated wetting without intervening stirring.

TABLE 4.—*Moisture content of the soil of six plots in field E–5, Prosser experiment farm, July 9, 1924, one day after an irrigation of 4.5 inches*

Plot	Inches of water per foot of soil at depth of—				
	1 foot	2 feet	3 feet	4 feet	Total moisture to 4-foot depth
A	3.05	2.14	1.25	1.39	7.83
B	2.82	2.16	.95	1.07	7.00
C	3.06	2.43	1.29	1.38	8.16
D	2.79	2.52	1.05	.99	7.35
E	2.67	2.02	1.13	1.15	6.97
F	2.95	2.12	1.32	1.31	7.70
Average	2.89	2.23	1.16	1.21	7.50

TABLE 5.—*Moisture content of the soil of six plots in field E–5, Prosser experiment farm, July 29, 1924, three weeks after an irrigation of 4.5 inches*

Plot	Inches of water per foot of soil at depth of—				
	1 foot	2 feet	3 feet	4 feet	Total moisture to 4-foot depth
A	1.62	1.77	1.34	1.36	6.09
B	1.40	1.83	1.46	1.31	6.00
C	1.37	1.71	1.38	1.20	5.66
D	1.55	1.61	1.53	1.34	6.23
E	1.50	1.75	1.42	1.36	6.03
F	1.46	1.70	1.45	1.39	6.00
Average	1.48	1.76	1.43	1.33	6.09

It was desired to observe the changes in the distribution of moisture in the soil and the losses that might occur by evaporation. The surface soil was not disturbed for about three weeks following the sampling on July 9, or until July 29, when another set of samples was taken. The results of the moisture determinations on these samples are given in Table 5. This table shows that during three weeks there was an average net loss of 1.5 inches of water from the 4-foot layer of soil. During the whole month of July for that year the loss by evaporation from a free-water surface was reported as 7.28 inches and the precipitation was 0.19 inch. It should be kept in mind that the quantity

here reported as lost from the soil was chiefly evaporation loss. There was practically no plant growth on these plots, and the slight change that occurred in the moisture content of the fourth foot indicates that there was probably very little increase in moisture below that depth. The decrease in moisture for the first foot was 1.41 inches. This is probably as close an approximation of the total evaporation loss as could be expected. The loss from the second foot was 0.47 inch, while the increase of moisture in the third and fourth sections was 0.39 inch. The inference is that approximately 1.5 inches was lost by evaporation, chiefly from the first foot, and that there was some readjustment of moisture from the second foot to the lower layers.

After the samples of soil were taken on July 29 the plots were left undisturbed for another three weeks, or until August 19 and 20, when another set of samples was taken. The moisture contents of these samples are given in Table 6. The average loss for the second period of three weeks was only 0.38 inch as compared with 1.51 inches for the previous three weeks. This loss was fairly well distributed through the 4-foot section. The evaporation loss from a free-water surface for the whole month of August was 6.18 inches. It seems probable that not all of the 0.38 inch reported as lost from the soil escaped by evaporation. The average net loss from the surface foot was 0.09 inch, and, while there may have been some replacement from below, it seems probable that there occurred also some further distribution of moisture downward to the soil below the fourth foot. One of the outstanding features shown by this series of tables is that the uncropped and undisturbed soil gives up its water very slowly, even during the hot, dry summer months.

TABLE 6.—*Moisture content of the soil of six plots in field E-5, Prosser experiment farm, August 19 and 20, 1924, six weeks after an irrigation of 4.5 inches*

Plot	Inches of water per foot of soil at depth of—				
	1 foot	2 feet	3 feet	4 feet	Total moisture to 4-foot depth
A	1.50	1.42	1.20	1.30	5.42
B	1.36	1.77	1.40	1.30	5.83
C	1.55	1.37	1.17	1.00	5.09
D	1.30	1.80	1.42	1.30	5.82
E	1.25	1.70	1.40	1.36	5.71
F	1.40	1.70	1.40	1.38	5.88
Average	1.39	1.63	1.33	1.27	5.62

The reports from the Prosser station indicate that during the month of August, 1924, the total precipitation was 0.65 inch, which occurred in two showers. This precipitation no doubt tended to reduce the net loss of water from the soil, but the summer showers of that region are usually so light and so quickly dissipated that their effect on soil-moisture conditions is almost negligible.

The results of the irrigation of July 8 may be briefly summarized as follows: Before irrigation the soil to the depth of 4 feet contained 3.38 inches of water. On the day following an irrigation of 4.5 inches there was a net increase of 4.12 inches, held chiefly in the upper 2 feet of soil. After three weeks there had been a net loss of 1.5 inches,

mostly from the first foot, with some movement of water downward from the second foot. During the next three weeks the net loss of water was only 0.38 inch, apparently contributed from the whole 4 feet of soil.

THE SECOND IRRIGATION OF 1924

After observing the changes in moisture conditions that took place during six weeks after an irrigation of 4.5 inches it was decided to extend the depth of sampling and to use larger quantities of water for irrigation. It seemed important to determine by repeated observations how much water would be held by the soil of a deep root zone, in order to estimate how much would be required to leach the root zone if such treatment were necessary as a means of replacing a superconcentrated soil solution. Where the system of irrigation is such that all of the water applied to the soil is held in the root zone to be subsequently dissipated by evaporation or absorbed by plants, it follows that the dissolved salts contained in the irrigation water remain in solution in the root zone. Thus, unless the root zone is leached occasionally, the solution finally becomes so concentrated with respect to these soluble salts that the crop plants are unable to absorb from it the water they require for the processes of growth.

The moisture conditions in the soil of the six basins to the depth of 6 feet were determined by means of duplicate samples taken on August 19 and 20, 1924. The results of these determinations are given in Table 7. This table shows that these plots contained on an average 8.28 inches of water in the soil to the depth of 6 feet. This was distributed fairly uniformly with slightly more in the second foot than in the other sections. From what is known of the water relations of this soil it is evident that it then contained approximately 4 inches of water that would be available to plants having a root system distributed throughout the 6 feet. In other words, it contained more water and had a correspondingly smaller capacity for storing the water of an irrigation than it would have had if covered by a growing crop in need of irrigation. This point should be kept in mind in considering the quantity of water required to leach the root zone of a soil from which nearly all of the available water has been absorbed.

TABLE 7.—*Moisture content of the soil of six plots in field E-5, Prosser experiment farm, August 19 and 20, 1924, before the second irrigation*

Plot	Inches of water per foot of soil at depth of—						
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth
A	1.50	1.42	1.20	1.30	1.25	1.22	7.89
B	1.36	1.77	1.40	1.30	1.16	1.31	8.30
C	1.55	1.37	1.17	1.00	1.19	1.34	7.62
D	1.30	1.80	1.42	1.30	1.55	1.48	8.85
E	1.25	1.70	1.40	1.36	1.30	1.28	8.29
F	1.40	1.70	1.40	1.38	1.50	1.36	8.74
Average	1.39	1.63	1.33	1.27	1.32	1.33	8.28

On August 21 four of the plots were irrigated, as follows: To plot A, 5 inches of water was applied; to plot B, 6.5 inches; to plot C, 11.5

inches; and to plot D, 8.8 inches. On August 22 the two remaining plots were irrigated, plot E being given 18 inches and plot F 12 inches. The soil absorbed the water readily, but the surfaces of plots E and F were so wet on the day following irrigation that the soil samples could not be taken until the second day. The first four plots were sampled in duplicate to the depth of 6 feet on August 22, and the last two were sampled in the same way on August 24. The results of the moisture determinations on these samples are given in Table 8.

TABLE 8.—*Moisture content of the soil of six plots on field E-5, Prosser experiment farm, August 22 and 24, 1924, immediately after the application of different quantities of irrigation water*

Plot	Inches of water per foot of soil at depth of—						Total moisture to 6-foot depth
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	
A	2.85	3.28	3.07	1.56	1.85	1.40	13.01
B	3.27	3.46	2.81	1.85	1.58	1.51	14.48
C	3.39	3.72	3.05	2.61	2.63	2.12	17.52
D	2.80	3.05	3.24	2.86	2.28	2.00	16.83
E	3.30	3.24	3.31	3.14	3.15	3.10	19.24
F	2.48	3.68	3.60	2.64	2.56	3.54	18.50
Average	3.01	3.51	3.01	2.44	2.34	2.28	16.60

In view of the fact that each plot was given a different quantity of water it is necessary to confine the comparison between conditions before and after irrigation to the individual plots, though the averages for each foot for all six plots are given in both tables.

For plot A, to which 5 inches of water was applied, the total increase in water was 5.12 inches, of which 4.08 inches was held in the first 3 feet. It is not clear that there was immediately any effective penetration below the sixth foot. For plot B, to which 6.5 inches was applied, the total increase reported was 6.18 inches, of which 5.01 inches was held in the first 3 feet. Here, again, there appears not to have been any effective percolation beyond the sixth foot at least since the moisture content of that layer of soil was still well below its field-carrying capacity, and the results indicate that it was increased by only 0.2 inch at the end of 24 hours after irrigation.

The application of 11.5 inches of water to plot C increased the total moisture supply by 9.9 inches. This would indicate that 1.6 inches had passed below the sixth foot in 24 hours, and it might be assumed that some leaching action had resulted.

From what is known of the process of leaching, based on laboratory work with soil columns as well as on field samplings, it is believed that the application of water to the surface of the soil is followed by a displacement downward of the original soil solution rather than the diffusion of the added water through the solution. These observations lead to the view that the water that percolates, for example, from the fourth foot into the fifth foot is largely composed of the soil solution originally held in the upper layers of the soil. Consequently, where there is evidence of a movement of water, as from the sixth foot

downward, it is assumed that such water contains not only the salt originally held in solution in the moisture of the sixth foot but also some additional salt brought down in solution from the upper soil.

On plot D the application of water was 8.8 inches, and the resulting increase in water content of the 6 feet of soil was 7.98 inches. Of this amount, 6.73 inches was retained, at least temporarily, in the first 4 feet of soil; and while the moisture content of the fifth and sixth feet was increased appreciably, it is not clear that there was much effective percolation below the sixth foot.

The irrigation of plot E was very heavy, 18 inches of water being used. This made the ground so soft that samples could not be taken until the second day after irrigation. The test of these samples indicated that the soil had been well filled with water, there being more than 3 inches in each foot, with a total increase of 10.95 inches for the 6-foot section. The difference between that quantity and the 18 inches applied was nearly as large as the quantity of water held in the section before irrigation. It seems probable that the solution originally present was very largely replaced by the water added, and consequently that a single irrigation of 18 inches on this soil would result in complete and effective leaching of the root zone to 6 feet at least.

Finally plot F was irrigated with 12 inches of water, of which 9.76 inches was retained in the upper 6 feet. It may be assumed that the original solution was almost completely displaced from the first 4 feet of soil and that approximately 3 inches of water, containing a substantial proportion of the dissolved salts originally in the root zone, passed below the limit of observation.

It may be recalled from Table 1 that the soil of these basins showed a moisture-equivalent capacity of 15.08 inches for the first 6 feet; that is to say, the soil of that section when tested in the laboratory held that equivalent of water against a force one thousand times that of gravity. The field observations as reported in Table 8 indicate that the soil may hold, for some hours at least, as much as 18 inehes of water against the force of gravity in the 6-foot section.

Following the sampling of August 22 and 24 the plots were left undisturbed for a week, or until August 30. On that date another set of duplicate samples was taken in order to determine what loss or redistribution of moisture had taken place. The results for this set of samples are given in Table 9. For the series of plots as a whole the average moisture content for the 6-foot section had decreased by 2.52 inches. This decrease was distributed as follows: From the first 2 feet, 0.73 inch for each; from the third foot, 0.57 inch; from the fourth foot, 0.27 inch; from the fifth foot, 0.19 inch; while from the sixth foot only 0.03 inch was lost.

The losses reported for the individual plots are less consistent than the averages for the 1-foot sections. They ranged from 1.35 inches for plot A to 4.23 for plot F. It is not apparent why the losses indicated for plot B, 2.91 inches, and for plot F, 4.23 inches, should be so much above the average. These are probably to be explained as examples of the aberrant results caused by very local differences in the texture of the soil associated with the isolated strata of fine silt referred to previously. A critical examination of Table 9 shows that if the lower 3 feet of plots A and B are eliminated from consideration, the average water content of the remaining plot sections is equivalent

to 2.49 inches per foot, while the average moisture equivalent as taken from Table 1 is 2.51 inches per foot. The reason for eliminating the lower sections of plots A and B from this comparison is that the quantity of irrigation water applied to these two plots was evidently not sufficient to saturate the whole 6-foot section. The comparison just made appears to warrant the assumption that the moisture equivalent of this soil as determined in the laboratory affords a fair basis for estimating its field-carrying capacity after conditions of equilibrium have become established. This is substantially the conclusion arrived at by Burr and Russel as a result of an extensive series of observations on the water relations of Nebraska soils.[5]

TABLE 9.—*Moisture content of the soil of six plots on field E–5, Prosser experiment farm, August 30, 1924, one week after the application of different quantities of irrigation water*

Plot	Inches of water per foot of soil at depth of—						
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth
A	2.29	2.21	2.08	1.93	1.89	1.26	11.66
B	2.18	2.73	1.99	1.53	1.66	1.48	11.57
C	2.21	3.47	2.59	2.46	2.02	2.63	15.38
D	2.30	2.63	2.44	2.22	2.79	2.40	14.78
E	2.47	3.25	3.20	2.26	2.44	3.18	16.80
F	2.25	2.42	2.34	2.61	2.10	2.55	14.27
Average	2.28	2.78	2.44	2.17	2.15	2.25	14.08

Finally, after the sampling of August 30 the plots were left undisturbed until October 1, a period of six weeks from the last irrigation. During the month of September the precipitation amounted to 0.69 inch, occurring in three showers, and the evaporation from a free-water surface was 3.71 inches for the month. The moisture condition in the plots on October 1, 1924, is shown in Table 10. During the five weeks following August 30 the average loss of water from the 6-foot section of each plot was 2.32 inches. This loss as shown by the averages was fairly well distributed throughout the upper 5 feet. The water content of the sixth foot was practically unchanged. It seems altogether probable that the larger part of the water lost was dissipated by evaporation, although there was doubtless some movement downward also. There was no crop growth to absorb moisture from the soil, though a few small weeds that were permitted to survive may have used some water.

It becomes apparent on comparing in detail the results presented in Tables 9 and 10 that the dissipation of water occurred by way of vaporization well below the surface of the soil; in other words, evaporation was not confined to the surface layer of soil. It appears to have been assumed by some investigators that the loss of water from the soil takes place as a result of evaporation at the soil surface, accompanied by the rise of water by capillarity from the lower soil to replace the evaporation losses. It is not to be questioned that in

[5] BURR, W. W., and RUSSEL, J. C. REPORT OF CERTAIN INVESTIGATIONS ON THE CENTRAL NEBRASKA SUPPLEMENTAL IRRIGATION PROJECT. Nebr. Dept. Public Works Bien. Rpt. (1923/24) 15: 199–240, illus. [1925].

some situations the evaporation of water is localized at or near the surface of the soil and that the supply to be vaporized in that area is maintained by capillary movement from the saturated subsoil. In such situations there is often formed a crust of salt on the soil surface, or a high proportion of soluble salt is found in a thin layer of surface soil. Such conditions are observed usually only where the subsoil is saturated with water not far below the surface and where the condition of saturation is maintained by hydrostatic pressure. When there is no zone of saturated subsoil within a very few feet of the surface the vaporization of soil moisture appears to take place well down in the soil, as well as at or near the surface. Under such conditions there is an appreciable circulation of air throughout the root zone, and in a moist soil the soil atmosphere is approximately saturated with water vapor. There is some basis both in laboratory experiments and in field observations for the view that the distribution of water through the root zone in the direction of establishing conditions of equilibrium takes place quite as much by alternate vaporization and condensation as by the capillary movement of liquid water.

TABLE 10.—*Moisture content of the soil of six plots on field E–5, Prosser experiment farm, October 1, 1924, six weeks after the application of different quantities of irrigation water*

Plot	Inches of water per foot of soil at depth of—						
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth
A	1.93	1.93	1.58	1.69	1.53	1.73	10.39
B	1.93	1.93	1.53	1.50	2.08	2.11	11.08
C	2.26	2.49	2.10	1.81	1.80	2.57	13.03
D	1.89	2.76	1.97	1.73	1.55	2.37	12.27
E	1.73	2.37	2.02	1.58	1.73	2.84	12.27
F	2.00	2.36	1.75	1.62	1.76	2.03	11.52
Average	1.96	2.31	1.82	1.65	1.74	2.27	11.76

The outstanding result of the observations reported in Table 10 is that six weeks after irrigation—a period of dry, warm weather—the soil of these plots still held nearly 12 inches of water in the first 6 feet, and that probably nearly 8 inches of that water could be regarded as available for the use of plants.

THE IRRIGATIONS OF 1925

It was desired, for the season of 1925, to determine what changes in moisture conditions in the six plots in field E–5 would follow from a regular sequence of irrigations on uncropped land. For this purpose the plots were grouped into adjacent pairs and to each pair was given a different quantity of water, though the number of irrigations was the same for all. The plots were irrigated seven times from April 27 to September 2, inclusive, the interval between irrigations being about three weeks. Plots A and B were given 4 inches of water at the first irrigation and 2 inches at each subsequent irrigation. Plots C and D were given 3.5 inches and plots E and F were given 5 inches

at each irrigation throughout the season. The plots were not cropped, and the weeds were kept down by pulling or hoeing. Samples of soil were taken in duplicate from each plot the day before and again the day after each irrigation.

During the period from May 1 to August 31, inclusive, the precipitation amounted to 0.94 inch. This occurred in the form of light showers, and it is believed that these did not affect materially the moisture conditions of the soil in the plots under observation. During the same period the total evaporation from a free-water surface was 24.76 inches.

The moisture conditions for the season of 1925, the averages for plots A and B to the depth of 6 feet are given in Table 11. The date given in the first column of the table is the date on which the plots were irrigated. The water content opposite the word "before" is that found the day before irrigation, while that opposite the word "after" is that found the day after irrigation. The data for the irrigation of April 27 are not included in the averages because a larger quantity of water was used then than later.

TABLE 11.—*Moisture content of the soil in plots A and B, field E–5, Prosser experiment farm, for the season of 1925, before and after each of seven irrigations, with a total application of 16 inches of water*

Date	Inches of water per foot of soil at depth of—						Total moisture to 6-foot depth	Increase	Decrease
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet			
Apr. 27:									
Before	1.76	1.89	1.55	1.60	1.81	1.96	10.47		
After	2.97	3.52	1.76	1.81	2.05	1.63	13.74	3.27	
May 20:									
Before	2.14	2.39	2.04	1.70	1.89	1.67	11.83		1.91
After	2.70	2.64	2.26	1.95	2.13	1.97	13.65	1.82	
June 12:									
Before	2.14	2.25	1.97	1.70	1.96	2.32	12.34		1.31
After	2.70	2.50	2.19	1.90	2.02	2.20	13.51	1.17	
July 2:									
Before	2.09	1.99	1.87	1.93	2.24	2.36	12.48		1.03
After	2.97	2.27	1.87	1.89	2.26	1.83	13.09	.61	
July 21:									
Before	1.85	2.05	1.80	1.71	2.03	1.74	11.18		1.91
After	2.88	2.65	1.71	1.60	2.06	1.80	12.70	1.52	
Aug. 12.									
Before	1.72	2.05	1.73	1.80	2.18	1.74	11.22		1.48
After	3.03	2.87	2.03	1.83	1.99	1.97	13.72	2.50	
Sept. 2:									
Before	1.92	2.33	1.89	1.65	2.02	1.96	11.77		1.95
After	2.89	2.54	2.08	1.79	2.08	1.90	13.28	1.51	
Average:[a]									
Before	1.98	2.18	1.88	1.75	2.05	1.96	11.80		
After	2.86	2.58	2.02	1.83	2.09	1.94	13.32		
Increase or decrease[b]	+.88	+.40	+.14	+.08	+.04	−.02	+1.52		

[a] The 4-inch irrigation of Apr. 27 is omitted from the averages.
[b] The difference between the average before irrigation and the average immediately afterwards.

While the detailed figures in this and the following tables show some irregularities characteristic of field observations of moisture conditions, it is believed that the averages at the bottom of the table give a fairly true picture of the changes that occurred. It will be noted that whereas the average application of water was estimated as 2 inckes in depth for each plot, the average increase in moisture content resulting from irrigation is given as 1.52 inches. It seems

hardly probable that the difference of 0.48 inch was lost by evaporation between the time of irrigation and the time of sampling the following day. The inference is that a part of the discrepancy may have been due to unavoidable errors either in measuring the irrigation water or in computing the moisture content of the soil. It does not seem probable that for these two plots there was an appreciable loss of water by percolation below the sixth foot, though there may have been during the season a slight increase in moisture below the sixth foot as a result of capillary movement or vaporization.

The averages of the increases in moisture content resulting from irrigation show a consistent decline from the first to the fifth foot. It is doubtful, however, whether the changes shown for the second 3 feet are to be regarded as of sufficient magnitude to be significant. In other words, this evidence appears to indicate that with irrigations of only 2 inches, even without crop absorptions, there was not much effect below the third foot.

The moisture conditions for the season for plots C and D are shown in Table 12. These plots were irrigated seven times with 3.5 inches

TABLE 12.—*Moisture content of the soil in plots C and D, field E-5, Prosser experiment farm, for the season of 1925, before and after each of seven irrigations, with a total application of 24.5 inches of water*

Date	Inches of water per foot of soil at depth of— 1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth	Increase	Decrease
Apr. 27:									
Before	1.78	2.20	1.94	1.71	1.76	1.94	11.33	------	------
After	3.06	3.66	2.47	2.19	1.65	1.77	14.80	3.47	------
May 20:									
Before	1.80	2.46	1.86	1.77	1.82	1.87	11.58	------	3.22
After	2.63	3.50	2.74	1.90	1.74	1.90	14.41	2.83	------
June 12:									
Before	2.03	2.83	2.29	2.17	1.81	2.17	13.30	------	1.11
After	2.60	3.15	2.83	2.56	2.41	2.46	16.01	2.71	------
July 2:									
Before	2.20	2.68	2.41	2.24	1.99	2.42	13.94	------	2.07
After	3.31	3.41	3.28	2.39	2.13	1.90	16.42	2.48	------
July 21:									
Before	1.83	2.34	2.29	1.69	1.87	2.10	12.12	------	4.30
After	3.16	3.51	2.78	2.06	1.73	2.04	15.28	3.16	------
Aug. 12:									
Before	2.07	2.42	2.10	1.73	1.65	2.20	12.17	------	3.11
After	2.97	3.32	2.88	2.42	2.32	2.38	16.29	4.12	------
Sept. 2:									
Before	1.92	2.61	2.29	1.93	1.94	2.33	13.02	------	3.27
After	3.28	3.49	2.74	2.15	2.01	2.26	15.93	2.91	------
Average:									
Before	1.95	2.51	2.17	1.89	1.83	2.15	12.49	------	------
After	3.00	3.43	2.82	2.24	2.00	2.10	15.59	------	------
Increase or decrease [a]	+1.05	+.92	+.65	+.35	+.17	−.05	+3.10	------	------

[a] The difference between the average before irrigation and the average immediately afterwards.

of water each time. The average increase in moisture content for the 6-foot section is given as 3.1 inches. Here again the average increase shown is less than the average estimated application of water. The average increase in moisture content for each successive section shows a progressive decline, with a very slight increase for the fifth foot and an insignificant difference for the sixth foot. The indications are that there was no leaching action, although at the end of the season the moisture content of the whole section was slightly higher than at the beginning.

The conditions in plots E and F are shown in Table 13. These plots received 5 inches of water at each of seven irrigations. The average increase in moisture content reported for each irrigation was 3.62 inches. It seems probable that there was some percolation or downward movement of water below the sixth foot. There was also an appreciable increase in moisture content in the 5-foot and 6-foot layers after each irrigation. These 5-inch irrigations, with no crop growth to use the water, appear to have been adequate to produce some leaching effect.

TABLE 13.—*Moisture content of the soil in plots E and F, field E–5, Prosser experiment farm, for the season of 1925, before and after each of seven irrigations, with a total application of 35 inches of water*

Date	Inches of water per foot of soil at depth of—						Total moisture to 6-foot depth	Increase	Decrease
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet			
Apr. 27:									
Before	1.61	2.13	2.17	1.76	1.69	2.34	11.60		
After	2.40	2.90	2.82	1.96	1.69	2.44	14.21	2.61	
May 20:									
Before	2.05	2.39	2.05	1.76	1.88	1.84	11.97		2.24
After	2.70	3.42	3.69	2.68	2.40	2.86	17.75	5.78	
June 12:									
Before	2.45	2.75	2.63	2.41	2.40	2.58	15.22		2.53
After	2.22	3.60	3.35	2.58	2.50	3.02	17.27	2.05	
July 2:									
Before	1.97	2.43	2.91	2.14	2.31	2.05	14.41		2.86
After	2.99	3.00	3.55	2.90	1.95	2.97	17.36	2.95	
July 21:									
Before	1.83	2.98	2.64	1.93	1.97	2.51	13.86		3.50
After	3.07	3.60	3.00	2.30	2.60	2.70	17.27	3.41	
Aug. 12:									
Before	1.92	2.39	2.33	1.91	1.88	2.76	13.19		4.08
After	2.96	4.14	3.50	2.80	2.12	2.63	18.15	4.96	
Sept. 2:									
Before	1.71	2.83	2.52	2.52	1.89	2.37	13.84		4.31
After	3.03	4.02	3.22	2.67	1.90	2.65	17.39	3.55	
Average:									
Before	1.92	2.56	2.46	2.06	2.00	2.44	13.44		
After	2.77	3.53	3.30	2.54	2.17	2.75	17.06		
Increase [a]	+.85	+.97	+.84	+.48	+.17	+.31	+3.62		

[a] The difference between the average before irrigation and the average immediately afterwards.

THE IRRIGATIONS OF 1926

In 1926 the irrigation experiments were continued on the same pairs of basins that were used in 1925. The same number of irrigations were given, and the same quantities of water were used except that on plots A and B the first irrigation was of 2 inches, like the later ones, instead of 4 inches as in 1925. Furthermore, in 1926 all the plots were planted to corn, while they were kept fallow in 1925. The corn crop did not do well and the plants did not make many ears. The whole crop was harvested for silage, and the green weights of yield were as follows: For plots A and B, 2,532 pounds per acre; for plots C and D, 3,288 pounds per acre; and for plots E and F, 3,000 pounds per acre. For May to August, inclusive, the precipitation was 2.32 inches, and the evaporation from a free water surface was 24.98 inches.

TABLE 14.—*Moisture content of the soil in plots A and B, field E–5, Prosser experiment farm, for the season of 1926, before and after each of seven irrigations, with a total application of 14 inches of water*

Date	Inches of water per foot of soil at depth of—							In-crease	De-crease
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth		
Apr. 28:									
Before	1.98	2.03	2.10	1.96	2.25	1.80	12.12		
After	3.47	3.65	2.64	2.03	2.10	1.60	15.40	3.37	
May 15:									
Before	2.46	2.35	1.96	2.25	2.55	2.60	14.17		1.32
After	3.07	3.30	2.12	2.00	2.20	2.05	14.74	.57	
June 6:									
Before	2.34	2.45	2.34	1.89	2.15	2.27	13.44		1.30
After	4.07	3.19	2.56	2.10	1.87	2.07	15.86	2.42	
June 26:									
Before	1.81	1.70	2.01	1.85	1.80	2.12	11.29		4.57
After	2.29	2.78	2.04	1.81	1.84	1.94	12.70	1.41	
July 17:									
Before	1.12	1.71	1.41	1.49	1.90	1.94	9.57		3.13
After	2.94	2.35	1.92	1.73	2.68	2.07	13.69	4.12	
Aug. 7:									
Before	1.04	1.57	1.68	1.80	2.21	2.01	10.31		3.38
After	2.82	1.96	1.56	1.61	2.18	1.93	12.06	1.75	
Aug. 30:									
Before	1.50	1.73	1.35	1.59	1.93	1.75	10.05		2.01
After	2.20	2.73	1.90	1.84	1.82	1.82	12.40	2.35	
Average:									
Before	1.75	1.93	1.86	1.83	2.11	2.07	11.56		
After	2.99	2.85	2.11	1.87	2.10	1.93	13.85		
Increase or decrease [a]	+1.24	+.92	+.25	+.04	−.01	−.14	+2.29		

[a] The difference between the average before irrigation and the average immediately afterwards.

The moisture conditions for plots A and B for 1926 are shown in Table 14. It was estimated that these plots received 2 inches of water at each irrigation, yet the average increase in water content as a result of irrigation is shown in the table to have been 2.29 inches. The figures for the average increases for each foot of soil show that there was little change in moisture content below the third foot. The fact that the average increase in moisture was greater than the average quantity applied as irrigation can be explained only as a discrepancy due to errors of water measurement or of soil sampling.

A comparison of conditions on these plots in 1925, as shown in Table 11, with those of 1926, as shown in Table 14, shows something of the effect of the corn crop on the moisture supply. Notwithstanding a higher average increase of moisture for each irrigation, the soil contained less water at the end of the crop season. This decrease in moisture supply was most pronounced in the upper 4 feet. There was very little difference in the lower layers. The data available do not warrant an attempt to estimate the quantity of water used by the crop in comparison with the quantity lost by direct evaporation. However, it is apparent from the figures given for the first and the second foot for 1926 that during the latter part of the season the soil was much drier than for the corresponding period of 1925.

13177—28——2

TABLE 15.—*Moisture content of the soil in plots C and D, field E–5, Prosser experiment farm, for the season of 1926, before and after each of seven irrigations, with a total of 24.5 inches of water*

Date	Inches of water per foot of soil at depth of—								
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth	Increase	Decrease
Apr. 28:									
Before	2.00	1.98	1.86	2.41	1.68	1.71	11.64		
After	3.03	3.65	3.60	1.81	1.71	1.71	15.51	3.87	
May 15:									
Before	2.54	3.06	2.27	1.85	1.79	2.35	13.86		1.03
After	3.38	4.02	2.98	1.60	1.92	2.17	16.07	2.19	
'une 6:									
Before	1.84	3.18	2.25	1.96	1.94	2.54	13.71		2.36
After	2.53	3.97	3.23	2.42	2.06	3.06	17.27	3.56	
une 20:									
Before	2.65	2.25	2.19	1.75	1.71	1.97	12.52		4.75
After	2.55	3.60	2.70	2.26	2.11	2.13	15.35	2.83	
uly 17:									
Before	1.01	2.13	2.00	1.79	1.61	1.92	10.46		4.89
After	3.36	3.61	2.68	2.08	1.98	2.15	15.86	5.40	
ug. 7:									
Before	1.24	1.87	1.91	1.54	1.67	1.79	10.02		5.84
After	2.86	2.49	2.24	2.28	1.96	1.96	13.79	3.77	
ug. 30:									
Before	1.44	2.27	1.70	1.54	1.65	2.10	10.76		3.03
After	2.25	3.72	2.67	2.04	1.83	2.14	14.65	3.89	
Average:									
Before	1.82	2.39	2.03	1.83	1.72	2.06	11.86		
After	2.85	3.58	2.87	2.07	1.94	2.19	15.50		
Increase[a]	+1.03	+1.19	+.84	+.24	+.22	+.13	+3.64		

[a] The difference between the average before irrigation and the average immediately afterwards.

On plots C and D the moisture conditions as shown in Table 15 /ere again different from those of 1925. The average increase in ıoisture content was 3.64 inches, while each irrigation was only 3.5 ıches. At the close of the season the soil contained less water than t the beginning. There was apparently some change in moisture ontent, resulting from irrigation, as far down as the fifth foot and ossibly even to the sixth foot. The largest changes were confined) the upper 3 feet. It is evident again in this table that the absorp-.on of water by the corn crop tended to lower the moisture content f the upper layers of the soil.

The moisture conditions for plots E and F for 1926 are shown in 'able 16. The average increase in moisture content resulting from rigation was 3.87 inches as compared with an estimated application f 5 inches. It is noticeable that for the whole 6-foot section there 'as not a decrease in moisture content during the season. In other 'ords, 35 inches of irrigation water was apparently sufficient to meet ıe evaporation losses and the growth requirements of the light crop f corn. It is quite possible also that there may have been some leach-ıg action, since the moisture content of the sixth foot appears to have een not far below what has been estimated as its field-carrying ıpacity.

DISCUSSION OF RESULTS

The soil used in the experiments here reported had a moisture ụuivalent of 16 per cent. A series of careful measurements showed ıat it could hold in the upper 6 feet about 16 inches of water, of

which about 12 inches could be used by plants. It was found that 1 inch of water added to the soil would increase the moisture content of 1 foot by 6 per cent or of the 6-foot section by 1 per cent. This is approximately the same relationship that has been found by the writers to obtain in other types of irrigated soil and that has been reported by other investigators.[6] It may be assumed as a general rule that with a wide range of soil types 1 inch of water in 1 foot of soil is equivalent to 6 per cent of the dry weight of the soil.

TABLE 16.—*Moisture content of the soil in plots E and F, Prosser experiment farm, for the season of 1926, before and after each of seven irrigations, with a total of 35 inches of water*

Date	Inches of water per foot of soil at depth of—							Increase	Decrease
	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	Total moisture to 6-foot depth		
Apr. 28:									
Before	2.35	1.06	2.00	1.80	1.60	2.02	11.75		
After	3.15	3.88	3.12	1.84	1.59	2.12	15.70	3.95	
May 15:									
Before	1.88	3.07	2.69	1.88	1.66	2.70	13.88		1.82
After	3.02	4.00	3.14	2.62	1.97	2.00	16.75	2.87	
June 6:									
Before	1.82	2.86	2.38	2.30	2.59	2.89	14.84		1.91
After	2.75	3.30	3.01	2.85	2.15	2.69	16.75	1.91	
June 28:									
Before	1.36	3.00	2.44	1.96	2.36	2.60	13.72		3.03
After	2.81	3.27	3.34	2.76	2.13	2.44	16.75	3.03	
July 17:									
Before	0.89	2.78	2.14	1.81	1.65	1.45	10.72		6.03
After	3.10	3.64	3.09	2.38	2.10	2.43	16.74	6.02	
Aug. 7:									
Before	1.62	2.55	2.02	1.77	1.82	2.81	12.59		4.16
After	2.91	3.18	2.63	2.24	2.02	2.31	15.29	2.70	
Aug. 30:									
Before	1.73	2.28	2.07	2.09	1.94	2.41	12.52		2.77
After	2.44	4.22	3.03	2.87	3.31	3.23	19.10	6.58	
Average:									
Before	1.66	2.65	2.25	1.94	1.95	2.41	12.86		
After	2.88	3.64	3.05	2.51	2.18	2.46	16.73		
Increase [a]	+1.22	+.99	+.80	+.57	+.23	+.05	+3.87		

[a] The difference between the average before irrigation and the average immediately afterwards.

There appears to be also a fairly close relationship between the moisture equivalent of a soil as determined in the laboratory and the field-carrying capacity. That is to say, a soil that has been pulverized and saturated with water as it is prepared for a test in the centrifugal machine will hold against a force one thousand times that of gravity about the same proportion of water as will be held against the force of gravity by the same soil as it occurs in the field.

There is some question as to whether it is safe to assume that the wilting coefficient as computed by dividing the moisture equivalent by 1.84 correctly represents the quantity of water that can be withheld by the soil from absorption by plants. To put the matter in another way: If it is assumed that the moisture equivalent may be taken as approximately the same as the field-carrying capacity, then the wilting coefficient may be computed by dividing the moisture equivalent by 1.84. If the wilting coefficient as determined by that

[6] ISRAELSEN, O. W., and WEST, F. L. WATER-HOLDING CAPACITY OF IRRIGATED SOILS. Utah Agr. Expt. Sta. Bul. 183, 24 p., illus. 1922.

computation be taken as the lower limit of available moisture, then the capacity of the soil for holding available water would be taken as the difference between the moisture equivalent and the wilting coefficient. This would indicate that if the soil were wet up to its field-carrying capacity, only about 45 per cent of the water would be available to crop plants. In these experiments it has been shown that the proportion of available water is not far from 70 per cent of the field-carrying capacity.

These considerations are, however, incidental to the chief purpose of the present inquiry. This purpose was to determine the water-holding capacity of the soil of the root zone with reference to leaching action. It is coming to be generally recognized that in irrigated soil the root zone must be leached from time to time in order to remove the salts brought in by the irrigation water. Irrigation waters differ from rain water in that they contain appreciable quantities of dissolved salts. These salts are not, in a large measure, absorbed by plants, and consequently they remain in the soil solution of the root zone. If the system of irrigation is such that all of the water applied is held in the root zone to be absorbed by plants or dissipated by vaporization, then each successive irrigation augments the salt content of the soil solution in the root zone. In time the soil solution becomes so concentrated with dissolved salts that crop plants are not able to absorb from it the water they need for the processes of growth. The only way that dissolved salts can be removed from the root zone is by leaching. This process involves the application of a quantity of irrigation water sufficient to exceed the field-carrying capacity and thereby displace the concentrated solution of the root zone.

Some irrigation waters contain as much as 1,000 parts per million of salts of high solubility. An acre-foot of water weighs approximately 2.72 million pounds. Consequently an acre-foot of water containing 1,000 parts per million of highly soluble salts carries 2,720 pounds of such salt. It is not uncommon in irrigated regions having a long growing season to use 3 acre-feet of water on each acre of land, applied in 8 to 10 irrigations. This means that the average application is 4 inches or less for each irrigation. This quantity of water is barely sufficient to supply the needs of the crop and the unavoidable evaporation losses. Consequently there is no leaching action and all of the salt brought in by the 3 acre-feet of irrigation water remains in the soil of the root zone, for the most part dissolved in the soil solution. Under such conditions as those just described the annual increase of salt in the root zone would be at the rate of 7,000 pounds (3.5 tons) per acre. It is obvious that such a course of events could not be continued for many years without disastrous results.

In the soil that has been used in the experiments here described the field-carrying capacity to the depth of 6 feet has been found to be about 16 inches of water or 1⅓ acre-feet. When the water available to crop plants has been exhausted the root zone contains less than 6 inches of water. If it is assumed that the soil is irrigated when its supply of water is diminished to about 6 inches in the upper 6 feet, then the soluble salts of the root zone are largely concentrated in this 6 inches of water. If there were 7,000 pounds of salts dissolved in 6 acre-inches of water, the concentration of the solution would be

to use salty water for irrigation it is imperative that it be used in quantities sufficient to leach the root zone from time to time. Furthermore, it is obvious that the more salt there is in irrigation water the more water must be used in order to keep the root zone leached and thus prevent the superconcentration of the soil solution.

SUMMARY

The soil used in these experiments is classed as a sandy loam having a moisture equivalent of about 16 per cent. It has been found that with this soil, as with many other types, the weight relationships are such that 1 inch of water in 1 foot of soil is equivalent to 6 per cent of the dry weight of the soil.

When the soil has been thoroughly irrigated it is found to hold about 16 inches of water in the first 6 feet. When the available supply of water has been absorbed, as by a crop of alfalfa, it still contains about 5 inches of water in the first 6 feet.

It is not good farming practice to postpone irrigation until all of the available water has been absorbed by the crop; consequently, when the indications are that irrigation is needed there probably remains at least 10 inches of water within the root zone. The application of 4 to 6 acre-inches of water at each irrigation during the growing season probably does not result in any effective leaching of the root zone. When the soil is very dry it may hold an irrigation of as much as 10 inches without leaching.

The indications are that when the soil contains less water than its field-carrying capacity, the loss of water by vaporization takes place not only at the soil surface but also well down in the soil. It seems probable also that the movement of water through the soil in the direction of establishing conditions of moisture equilibrium, when the moisture content is below the field-carrying capacity, takes place not so much by capillarity as by vaporization and subsequent condensation.

With this soil, at least, the proportion of water available to crop plants (i. e., to alfalfa) is about 70 per cent of the field-carrying capacity, rather than about 45 per cent, as would be inferred by computing the wilting coefficient from the moisture equivalent.

In order to leach the root zone and thus remove the highly soluble salts brought in by the irrigation water, it is necessary to apply more water than is customarily used to supply the needs of crop plants. If the irrigation water is salty, the root zone must be leached more frequently than when purer water is used.

DIETARY REQUIREMENTS FOR FERTILITY AND LACTATION: A DIETARY STERILITY ASSOCIATED WITH VITAMIN A DEFICIENCY[1]

By BARNETT SURE

Professor of Agricultural Chemistry, Arkansas Agricultural College

INTRODUCTION

In previous communications conclusive evidence was presented of the existence of a specific vitamin for reproduction, designated as vitamin E (*6, 7, 8*).[2] [3] Among rats on a diet furnishing an abundance of fat-soluble vitamins A and D in the form of cod-liver oil female sterility was observed, characterized by resorption of the fetus during gestation, which was prevented by the addition of wheat oil, or small amounts of unsaponifiable matter therefrom, to the sterility-producing diet. The resorption of the embryos was determined by the character of the gestation curve during the period of advanced pregnancy and by a post-mortem examination of the uterine horns (*10*).

The composition of the ration which has never failed to produce sterility is as follows: Skim-milk powder, 50 per cent; agar-agar, 2; ferric citrate, 0.2; Harris yeast, 1; cod-liver oil, 2; dextrin, 44.8. The simple expedient of adding 3 per cent wheat oil (replacing an equivalent amount of dextrin in the ration) to such a dietary régime resulted not only in continuous fertility but also in normal lactation, and in healthy, vigorous succeeding generations. Fifth-generation animals that made growth far superior to that indicated by the Donaldson standard have been secured on the diet containing wheat oil, which has been found to be the most potent source of vitamin E (*10*).

In a recent study of vitamin E potency of butter fat (*12*), the writer has reported experimental results on a different dietary régime, showing that continuous fertility can be much more certainly assured by supplementary administrations of cod-liver oil (to furnish vitamins A and D) to pregnant females receiving 5 per cent butter fat in the ration as the only source of all known fat-soluble vitamins. The need of vitamin A as well as vitamin E in fertility was anticipated but no conclusive evidence was then available.

EXPERIMENTAL DATA

In the present report positive evidence is submitted associating female sterility with vitamin A deficiency, which is, so far as the writer has been able to determine, identical in every respect with that produced by a deficiency of vitamin E. The ration used in the experimental feeding (No. 835) was composed of the following: Skim-

[1] Received for publication May 14, 1928; issued October, 1928. Research Paper No. 63, Journal Series, University of Arkansas. This report is the seventeenth of a series on dietary requirements for reproduction. The previous papers of the series have appeared for the most part in the Journal of Biological Chemistry.

[2] Reference is made by number (italic) to "Literature cited," p. 91.

[3] Report presented before the Biochemical Division of the American Chemical Society at Milwaukee, Sept. 23, 1923.

milk powder (produced from summer milk) 50 per cent; agar-agar, 2; ferric citrate, 0.2; wheat oil, 3; Harris yeast, 1[4]; dextrin, 43.8. This ration contains an abundance of vitamin E. The writer was very much surprised to find that in this ration, which contained no cod-liver oil, two females out of three gave birth to first, second, and third

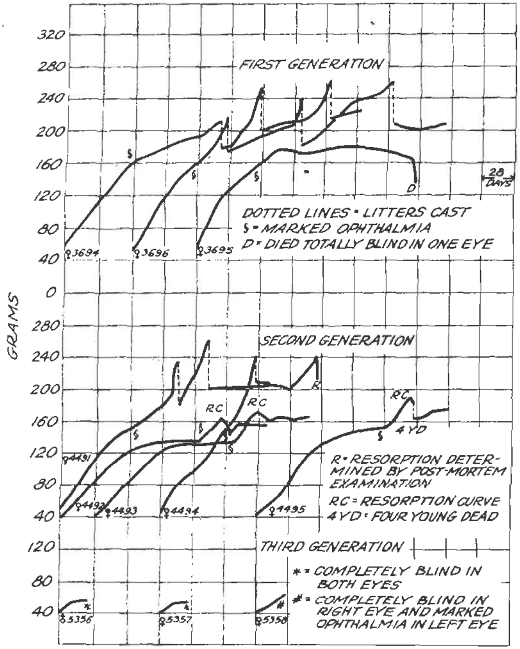

FIG. 1.—Reproduction records of rats on ration 835, adequate in vitamin E but deficient in vitamin A

litters each, and successfully weaned 15 young out of 35 allowed to be reared. These animals must have secured all of their needed vitamins A and D from what they had stored from the previous dietary and what additional amounts they derived from the skim-milk powder and wheat oil. It will be noted, however, that one female (fig. 1)

[4] From weaning time up to the beginning of the reproduction period the ration contained 0.4 per cent Harris yeast. The increase was made at the time of mating and that percentage left in the ration until

finally succumbed to vitamin A deficiency, having died with pronounced ophthalmia following a rapid loss of body weight. The character of the results on continuous fertility secured with females 3694 and 3696 on ration 835 warranted the continuation of this experiment for succeeding generations. The third litter of female 3694, which consisted of one male and five females, was taken for this purpose.

TABLE 1.—*Fertility and lactation records of females on ration 835, adequate vitamin E but deficient in vitamin A*

FIRST GENERATION

Female No.	Litter	Number of young born	Number of young born alive	Number of young allowed to be reared	Number of young weaned	Per cent of young weaned	Remarks
3694	*First*	5	5	0	0	0	
	Second	9	9	6	3	50	
	Third	6	6	6	0	0	
3695	0	0	0	0	0	0	No signs of advanced pregnancy during the breeding period of 143 days. Died completely blind in one eye.
3696	First	9	9	6	6	100	Weaned litter in 28 days.
	Second	9	9	6	0	0	
	Third	8	8	6	6	100	Weaned litter in 24 days at a normal rate.

SECOND GENERATION (THIRD LITTER OF FEMALE 3696)

Female No.	Litter	Number of young born	Number of young born alive	Number of young allowed to be reared	Number of young weaned	Per cent of young weaned	Remarks
4491	First	7	7	6	0	0	
	Second	10	10	6	0	0	
4492	0	0	0	0	0	0	Animal showed typical resorption curve.
4493	0	0	0	0	0	0	Animal showed typical resorption curve. Incipient ophthalmia in both eyes 8 days before termination of experiment.
4494	First	8	6	6	6	100	Reared first litter in 28 days. Resorbed second litter, as determined by post-mortem examination (fig. 1). At the time of resorption mother showed pronounced ophthalmia in both eyes.
4495	First	4	0	0	0	0	Prior to the birth of the 4 dead young this female showed a resorption curve.

Figure 1 and Table 1 show clearly that, on the whole, the reproduction record of the second generation was a failure. Although one female had two litters, two animals produced no young, having shown resorption curves [5] indicating that implantation occurred but that the products of conception were resorbed. One female out of the five, No. 4494, had a normal first litter but resorbed the second litter, as determined by post-mortem examination and a study of the uterine horns. Figure 2 shows a photograph of the uterine horns containing the embryos that have undergone a process of resorption for 72 hours.

[5] A few words of explanation are necessary regarding the meaning of "resorption curves," referred to in the text, in Table 1, and in Figure 1. During the seventeenth to nineteenth day of gestation females manifest unmistakable external signs of advanced pregnancy. At this stage they are placed in individual compartments and are given nests of shavings and excelsior in galvanized boxes. From then on they are weighed daily. When normal fertility proceeds, the mother gains most markedly during the last three to five days of gestation and the birth of the litter is followed by a precipitous drop in weight. When, however, resorption of the embryos occurs the mother instead of gaining markedly during the latter period of pregnancy loses gradually in weight, 6 to 12 gm. in 24 hours and all signs of advanced pregnancy disappear. When such animals are killed the embryos are invariably found in a process of resorption in the uterine horns, and the growth curve shown by such individuals is what the author has previously described as the "resorption curve." Considerable experience in the field justifies the writer in concluding from an analysis of the pregnancy curves and daily observations of the animals that the character of sterility of females 4492 and 4493 was that of resorption.

The character of this picture indicates a condition identical with that manifested by resorption of the fetus during gestation produced by a deficiency of vitamin E demonstrated in a previous communication (*10*). During the stage of resorption this animal showed marked ophthalmia in both eyes, indicating vitamin A deficiency. Female 4493 showed incipient ophthalmia in both eyes during the last eight days of the experiment. The male of this experiment, while showing excellent growth throughout the whole period of the study, suddenly developed an accentuated condition of ophthalmia in both eyes several days before the termination of the investigation. Female 4495 had only one litter of four young which were born dead.

Out of a total of three litters cast only one was successfully weaned (the first litter of female 4494). This litter consisted of four males and two females, but since the purpose of the study was to determine the effect of ration 835 on the reproductive capacity of succeeding generations, the two females and one male only were taken for the third generation. In less than four weeks male 5356 and female 5357 developed ophthalmia so severely in both eyes that they

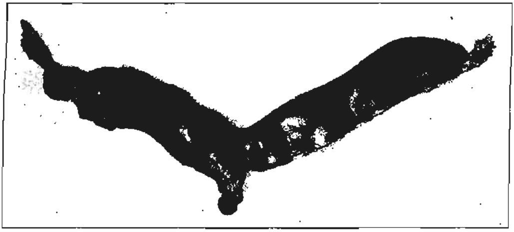

FIG. 2.—Uterine horns of female 4494 containing embryos that have undergone a process of resorption for 72 hours. Photographed by David G. Hall of the Department of Entomology, University of Arkansas

became completely blind, and female 5358 became completely blind in the right eye and showed marked ophthalmia in the left eye. The marked eye lesions were preceded by a cessation in growth in two animals out of the three.

DISCUSSION

The experimental data submitted show clearly that skim-milk powder ration 835, containing 3 per cent wheat oil, furnished considerable amounts of vitamin A for first and second generation animals. That it failed to furnish a sufficient quantity of this vitamin, however, became quite apparent in the second generation and most marked in the third. According to Sherman and MacLeod, skim-milk powder contains 10 per cent as much vitamin A as does whole-milk powder (*5*). The skim-milk powder of ration 835 must, therefore, have furnished some vitamin A, but certainly not enough to have allowed such excellent growth for a long period during the first and second generations. The author is, therefore, obliged to conclude that wheat oil contains considerably more vitamin A than

is reported in the literature. Quantitative biological studies on the vitamin A content of wheat oil, the results of which are described in the paper accompanying (*13*) revealed the fact that this oil, the most potent source of vitamin E previously demonstrated by Evans and Bishop (*2*), by the author (*9*), and by Evans and Burr (*3*), contains appreciable amounts of the A vitamin. Such results are at variance with preliminary qualitative data reported during last year (*11*).

In 1925 Sherman and MacLeod (*5*) from their studies of the relation of vitamin A to growth, reproduction, and longevity concluded that diets deficient in vitamin A, but which they claim were satisfactory in vitamin E, impaired fertility. These investigators did not determine, however, the character of the sterility they encountered.

According to Evans and Bishop (*1*), a deficiency of vitamin A produces in females a disturbance of oestrus which is highly characteristic of vitamin A avitaminosis. They find that "it consists in the prolongation of the oestrous desquamative change in the vaginal epithelium, the smear consisting chiefly, if not exclusively, of the cornified cells which in normal individuals characterize the actual period of oestrus and ovulation only, but which, in the case of animals showing vitamine A deficiency, occur throughout the entire period of acute deficiency." From such findings it is quite apparent that when there is an early depletion of vitamin A in the first generation oestrus and ovulation are disturbed and no fertilization is possible; hence, the sterility resembles in character that produced by vitamin B deficiency (*1*). The latter condition is precisely what was recently reported by Parkes and Drummond (*4*) in their study "The Effects of Fat-soluble Vitamin A Deficiency on Reproduction in the Rat." These authors concluded that "the sterility was due, primarily, to physiological debility and disinclination to copulate."

It is quite evident from Table 1 and Figures 1 and 2 that the character of sterility encountered in the present study is specifically associated with resorption of the fetus during gestation. The finding of ophthalmia in the sterile females during periods of resorption of the embryos on a diet abundant in vitamin E warrants the conclusion that the sterility encountered on ration 835 (from which cod-liver oil was absent) was produced by vitamin A deficiency.

SUMMARY

Sterility, characterized by resorption of the fetus during gestation, and associated with vitamin A deficiency, has been produced in rats on a skim-milk powder diet containing an abundance of vitamin E.

LITERATURE CITED

(1) Evans, H. M., and Bishop, K. S.
1922. ON THE RELATIONS BETWEEN FERTILITY AND NUTRITION. II.—THE OVULATION RHYTHM IN THE RAT ON INADEQUATE NUTRITIONAL REGIMES. Jour. Metabolic Research 1: 335–356, illus.

(2) ——— and Bishop, K. S.
1923. EXISTENCE OF A HITHERTO UNKNOWN DIETARY FACTOR ESSENTIAL FOR REPRODUCTION. Jour. Amer. Med. Assoc. 81: 889–892.

(3) ——— and Burr, G. O.
1927. THE ANTISTERILITY VITAMINE FAT SOLUBLE E. Calif. Univ. Mem. 8, 176 p., illus.

(4) Parkes, A. S., and Drummond, J. C.
1926. THE EFFECTS OF FAT-SOLUBLE VITAMIN A DEFICIENCY ON REPRODUCTION IN THE RAT. Brit. Jour. Expt. Biol. 3: 251–273, illus.

(5) Sherman, H. C., and MacLeod, F. L.
1925. THE RELATION OF VITAMIN A TO GROWTH, REPRODUCTION AND LONGEVITY. Jour. Amer. Chem. Soc. 47: 1658–1662, illus.

(6) Sure, B.
1924. DIETARY REQUIREMENTS FOR REPRODUCTION. II. THE EXISTENCE OF A SPECIFIC VITAMIN FOR REPRODUCTION. Jour. Biol. Chem. 58: 693–709, illus.

(7) ———
1924. DIETARY REQUIREMENTS FOR REPRODUCTION. III. THE EXISTENCE OF THE REPRODUCTIVE DIETARY COMPLEX (VITAMIN E) IN THE ETHEREAL EXTRACTS OF YELLOW CORN, WHEAT EMBRYO, AND HEMP-SEED. Jour. Biol. Chem. 62: 371–396, illus.

(8) ———
1925. DIETARY REQUIREMENTS FOR REPRODUCTION. IV. SOLUBILITY OF THE REPRODUCTIVE DIETARY COMPLEX (VITAMIN E) IN VARIOUS ORGANIC SOLVENTS. Jour. Biol. Chem. 63: 211–223, illus.

(9) ———
1926. DIETARY REQUIREMENTS FOR REPRODUCTION. V. THE RÔLE OF VARIOUS VEGETABLE AND FRUIT OILS IN FERTILITY AND LACTATION. Jour. Biol. Chem. 69: 29–40.

(10) ———
1926. DIETARY REQUIREMENTS FOR REPRODUCTION. VI. TYPES OF STERILITY PRODUCED ON A SKIMMED MILK POWDER REPRODUCTION-DEFICIENT DIET. Jour. Biol. Chem. 69: 41–51, illus.

(11) ———
1927. DIETARY REQUIREMENTS FOR REPRODUCTION. IX. COD LIVER OIL VERSUS WHEAT OIL AS SOURCES OF VITAMIN E. Jour. Biol. Chem. 74: 45–53.

(12) ———
1927. DIETARY REQUIREMENTS FOR REPRODUCTION. XI. THE POTENCY *OF BUTTER FAT IN VITAMIN E. Jour. Biol. Chem. 74: 71–84.*

(13) ———
1928. DIETARY REQUIREMENTS FOR FERTILITY AND LACTATION: THE VITAMIN A CONTENT OF WHEAT OIL. Jour. Agr. Research 37: 93–99, illus.

DIETARY REQUIREMENTS FOR FERTILITY AND LACTATION: THE VITAMIN A CONTENT OF WHEAT OIL[1]

By Barnett Sure

Professor of Agricultural Chemistry, Arkansas Agricultural College

INTRODUCTION

The early work of McCollum, Simmonds, and Pitz on "The Nature of the Dietary Deficiencies of the Wheat Embryo" (*3*)[2] suggested a toxic factor in wheat oil, and possibly for this reason investigators have been discouraged from attempting a quantitative study of the vitamin-A content of this oil. The researches of Osborne and Mendel (*5*) and Voegtlin and Myers (*13*), however, did not disclose a toxic factor in the oil of the wheat embryo. In the reproduction studies of the writer during the past five years more than 12 gallons of wheat oil have been used, and the introduction of as much as 3 per cent of this oil in the diets of rats has not resulted in an impairment of growth, fertility, or lactation, even when the animals were carried as far as the fifth generation (*10*). Recently Simmonds, Becker, and McCollum (*6*) have reported the beneficial effects of wheat oil when added to a "so-called salt ophthalmia-producing ration." The toxicity theory of McCollum and his associates concerning wheat oil promulgated in 1916 can, therefore, be abandoned.

Last year Steenbock and Coward (*7*) developed a quantitative method for the determination of vitamin A, which method insures the provision of vitamin D by irradiating the ration, and with their technic these authors demonstrated that of the three cereals—oats, wheat, and corn—wheat is the most potent in vitamin A. They have not, however, studied the oil of the wheat embryo, which is the source of the fat-soluble vitamins of the wheat kernel.

Since wheat oil is at present used by a number of nutritional investigators as a source of vitamin E, any data concerning its content of additional vitamins should be of interest to these workers, and such information may also serve as a guide in constructing rations deficient in all known fat-soluble vitamins other than E. Simmonds, Becker, and McCollum (*6*) and Mattill (*4*) assume in their recently published papers that wheat oil is quite deficient in vitamin A, and this assumption undoubtedly influenced the interpretation of their experimental findings. In the present communication quantitative data are presented showing that wheat oil, the most potent source of vitamin E, contains appreciable amounts of vitamin A.

[1] Received for publication May 14, 1928; issued October, 1928. Research paper No. 64, Journal Series University of Arkansas. This report is the eighteenth of a series on dietary requirements for reproduction. (See footnote 1, p. 87.)

[2] Reference is made by number (italic) to "Literature cited," p. 98.

Journal of Agricultural Research,
Washington, D. C.

Vol. 37, No. 2
July 15, 1928
Key No. Ark.-10

METHOD OF STUDY

Young nursing albino rats whose maternal diet was deficient in fat-soluble vitamins (*12*) were allowed to remain with the lactating mothers on the same ration for one to two weeks after weaning until unmistakable symptoms of ophthalmia developed, indicating a depletion of vitamin A. The composition of the fat-soluble-deficient diet (No. 1034) used in these experiments was as follows: Casein,[3] 20 per cent; McCollum's salts No. 185, 4 per cent; yeast,[4] 10 per cent; and dextrin, 66 per cent. The animals were from 5 to 6 weeks old at the time the experiments were started. The character of the eye lesions varied in intensity among the different individuals. Only one animal of the entire group showed no signs of ophthalmia at the beginning of the experiment. At the onset of ophthalmia all the animals had shown a complete cessation of growth. The curative method was then adopted, and wheat oil was daily administered separately from the ration to each animal in graduated amounts with a calibrated pipette. As controls, litter mates were employed which received comparable amounts of a cod-liver oil in use in this laboratory since 1921 (*11*). The wheat oil was prepared by percolating whole-wheat embryo with cold acetone by methods previously described (*9*), and was fed in dosages of 0.01 c. c., 0.05 c. c., and 0.1 c. c. per animal per day. The cod-liver oil was fed in dosages of 0.01 c. c., and 0.05 c. c. daily to each rat. Since it was believed that a daily allowance of 0.05 c. c. of cod-liver oil per animal would supply an optimum amount of vitamin A, the 0.1 c. c. cod-liver oil dosage was not tried. The animals were weighed twice a week (and in some cases when necessary three and four times a week) and food-consumption records (Table 1) were taken simultaneously with the records of body weight. The results of the feeding experiments are shown in Figures 1 to 3.

TABLE 1.—*Weekly food-consumption records of ophthalmic rats on a diet containing wheat oil or cod-liver oil as sources of vitamin A*

Animal No.	Number of grams of food consumed during—																								
	1st week	2d week	3d week	4th week	5th week	6th week	7th week	8th week	9th week	10th week	11th week	12th week	13th week	14th week	15th week	16th week	17th week	18th week	19th week	20th week	21st week	22d week	23d week	24th week	25th week
4751	[a]10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4752	[a]6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4757	34	38	45	38	38	35	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4758	30	32	31	50	43	33	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4749	47	64	100	100	95	96	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4750	43	62	99	70	73	74	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4763	32	48	63	64	64	40	78	100	93	88	95	99	100	98	102	67	77	85	47	52	53	19	...	...	...
4764	24	43	54	41	56	51	68	79	41	64	65	70	67	69	65	56	65	70	51	68	79	70	69	71	64
4761	50	77	68	85	103	96	90	79	69	78	75	80	80	100	97	81	78	88	80	86	84	65	67	73	70
4762	46	72	81	72	86	85	68	85	81	73	75	79	67	89	83	66	70	76	70	72	67	69	60	63	75
4753	[a]3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4754	30	47	51	66	79	76	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4765	50	75	65	63	46	60	83	103	96	93	94	96	45	100	108	83	85	93	86	92	77	56	...	...	...
4766	47	65	44	52	42	47	75	92	85	68	87	90	55	86	90	65	78	81	67	76	94	65	43	[b]0	...

[a] Food consumption record for a 5-day period. [b] Food consumption record for a 4-day period.

[3] Purified by repeated extraction with hot 95 per cent alcohol.
[4] Obtained from a commercial yeast manufacturing company.

EXPERIMENTAL RESULTS

It is quite clear from a study of Figure 1 that 0.01 c. c. wheat oil does not begin to compare with 0.01 c. c. cod-liver oil per animal per day as a source of vitamin A. Note, however, the response of

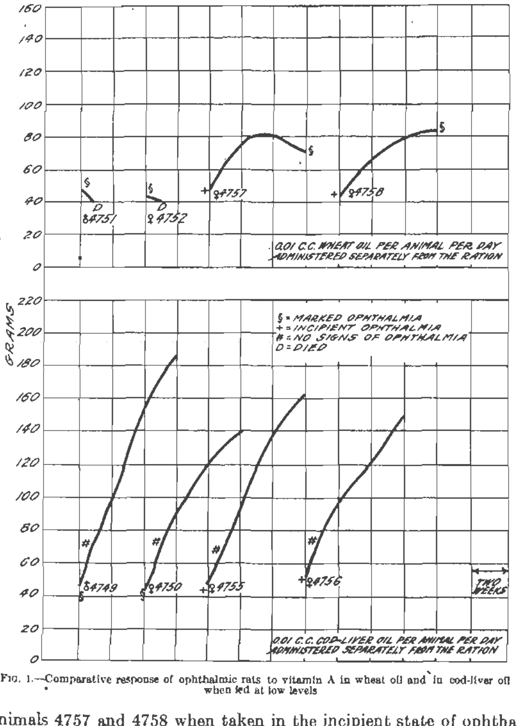

FIG. 1.—Comparative response of ophthalmic rats to vitamin A in wheat oil and in cod-liver oil when fed at low levels

animals 4757 and 4758 when taken in the incipient state of ophthalmia. Growth for two to four weeks is quite apparent.

Male 4763 and female 4764 (fig. 2), which at the beginning of the experiment were severely affected by ophthalmia and had already ceased to grow, showed a marked response to the daily administra-

tion of 0.05 c. c. wheat oil. Not only did the severe eye lesions entirely clear up in less than four weeks, but excellent growth was obtained in male 4763 for 16 weeks and very good growth in female 4764 for a period of 10 weeks. Animal 4763 finally succumbed, dying totally blind in both eyes when both animals 4761 and 4762

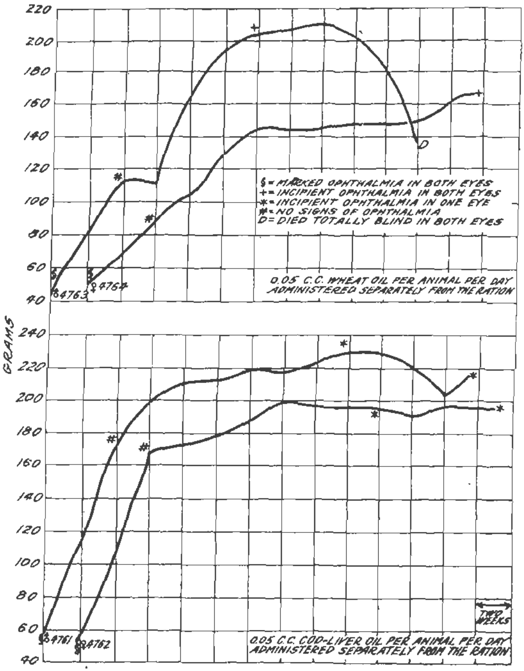

FIG. 2.—Comparative response of ophthalmic rats to vitamin A in wheat oil and in cod-liver oil when fed at levels higher than those represented in Fig. 1. The severity of the eye lesions in animals 4761 and 4762 was much greater than in animals 4763 and 4764. The former animals were almost blind in both eyes when the experiment began. *This fact probably explains the longer* period required for their eyes to heal

on an equivalent daily allowance of cod-liver oil were in excellent physical condition although showing incipent ophthalmia in one eye. From such results it is concluded that the optimum daily dosage of cod-liver oil for the adult rat is probably nearer 0.1 c. c. than 0.05 c. c. The *ophthalmic condition of female 4764 on the 0.05 c. c.*

wheat oil daily dosage was no worse than that of the two animals (4761 and 4762) receiving the equivalent cod-liver oil daily allowance, but the growth of No. 4764 was quite inferior. This experiment shows conclusively, then, the appreciable amounts of vitamin A in the oil of the wheat embryo.

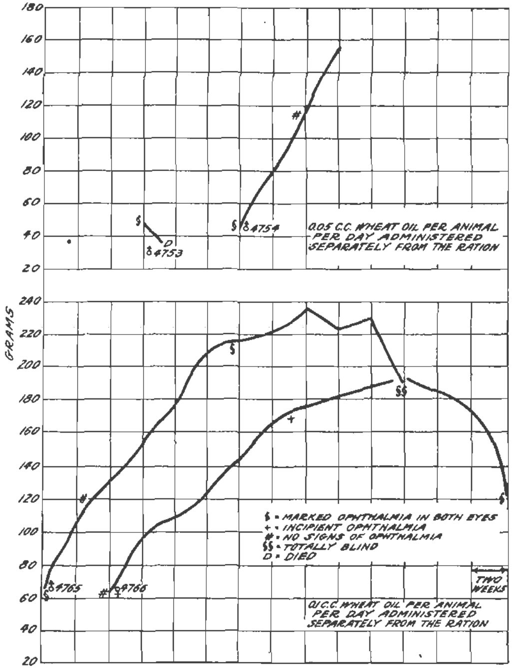

FIG. 3.—Comparative response of ophthalmic rats to vitamin A in wheat oil when fed at high levels

A daily dosage of 0.05 c. c. of wheat oil administered to male 4754 (fig. 3), started on the experiment in the incipient stage of opthalmia and at a period of maintenance of growth, resulted in rapid growth, which was continuous for a period of six weeks. All signs of eye lesions completely disappeared in less than four weeks. The same daily dosage of wheat oil was ineffectual, however, as a thera-

peutic measure in curing a case of severe ophthalmia (male 4753). A daily dosage of 0.1 c. c. of wheat oil was potent to the extent of entirely clearing up an advanced stage of ophthalmia in 17 days. On such a daily dosage excellent growth was produced for four months, after which period the animals gradually declined in growth and finally collapsed.

Table 1 shows that variations in growth of the individuals can very well be ascribed to variations in food consumption. The point that this table brings out is that before failure on the wheat-oil administrations sets in when the severe ophthalmia manifests itself, showing unmistakably a deficiency of vitamin A, there is a marked reduction of the food intake, until at the very last stage of the avitaminosis complete inanition occurs. Animal 4763 (fig. 2) ate only 1 gm. of food during the last four days of the experiment and animal 4766 ate absolutely nothing during the last three days of the experiment and only 4 gm. during the preceding two days. These findings have considerable significance in the etiology of anorexia, or loss of appetite. For some time it has been known that vitamin B has a controlling effect on food consumption (*1*, *2*) and recent work from this laboratory has demonstrated that as little as 5 mgm. of a highly concentrated vitamin B preparation from yeast can bring about a resumption of appetite at a state of complete inanition in 24 hours, but from the work reported in this paper it seems that a deficiency of fat-soluble vitamin A also plays a determining rôle in inanition. To be sure, in this series of experiments ample provision has not been made for the D vitamin, but since this vitamin, according to Steenbock and Nelson (*8*), is also essential for growth, the animals on ration 1034, deficient in fat-soluble vitamins, must have been deriving considerable vitamin D during the four months of their excellent growth from the supplementary daily administration of wheat oil. It would seem, then, that wheat oil also contains appreciable amounts of vitamin D. Work in progress shows that in cases of uncomplicated vitamin A deficiency, the D vitamin having been provided by the irradiated ration, a gradual reduction in food consumption occurs.

SUMMARY

A dosage of 0.05 c.c. of wheat oil per animal per day furnishes enough vitamin A for excellent growth for a period of 10 to 16 weeks. Such a dosage also serves as a potent therapeutic agent for curing severe eye lesions in animals produced by previous depletion of vitamin A.

The depletion of vitamin A is accompanied by inanition, a symptom heretofore associated only with vitamin B deficiency.

LITERATURE CITED

(1) COWGILL, G. R., DEUEL, H. J., Jr., and SMITH, A. H.
1925. STUDIES IN THE PHYSIOLOGY OF VITAMINS. XXX.—QUANTITATIVE ASPECTS OF THE RELATION BETWEEN VITAMIN B AND APPETITE IN THE DOG. Amer. Jour. Physiol. 73: 106–126, illus.

(2) KARR, W. G.
1920. SOME EFFECTS OF WATER-SOLUBLE VITAMINE UPON NUTRITION. Jour. Biol. Chem. 44: 255–276, illus.

(3) McCOLLUM, E. V., SIMMONDS, N., and PITZ, W.
1916. THE NATURE OF THE DIETARY DEFICIENCIES OF THE WHEAT EMBRYO. Jour. Biol. Chem. 25: 105–131, illus.

(4) MATTILL, H. A.
1927. THE OXIDATIVE DESTRUCTION OF VITAMINS A AND E AND THE PROTECTIVE ACTION OF CERTAIN VEGETABLE OILS. Jour. Amer. Med. Assoc. 89: 1505–1508.

(5) OSBORNE, T. B., and MENDEL, L. B.
1919. THE NUTRITIVE VALUE OF THE WHEAT KERNEL AND ITS MILLING PRODUCTS. Jour. Biol. Chem. 37: 557–601, illus.

(6) SIMMONDS, N., BECKER, J. E., and MCCOLLUM, E. V.
1927. THE RELATION OF VITAMIN E TO IRON ASSIMILATION. Jour. Amer. Med. Assoc. 88: [1047]–1050, illus.

(7) STEENBOCK, H., and COWARD, K. H.
1927. FAT-SOLUBLE VITAMINS. XXVII. THE QUANTITATIVE DETERMINATION OF VITAMIN A. Jour. Biol. Chem. 72: 765–779, illus.

(8) ——— and NELSON, E. M.
1923. FAT-SOLUBLE VITAMINS. XIII. LIGHT IN ITS RELATION TO OPHTHALMIA AND GROWTH. Jour. Biol. Chem. 56: 355–373, illus.

(9) SURE, B.
1926. DIETARY REQUIREMENTS FOR REPRODUCTION. V. THE RÔLE OF VARIOUS VEGETABLE AND FRUIT OILS IN FERTILITY AND LACTATION. Jour. Biol. Chem. 69: 29–40.

(10) ———
1926. DIETARY REQUIREMENTS FOR REPRODUCTION. VI. TYPES OF STERILITY PRODUCED ON A SKIMMED MILK POWDER REPRODUCTION-DEFICIENT DIET. Jour. Biol. Chem. 69: 41–51, illus.

(11) ———
1927. DIETARY REQUIREMENTS FOR REPRODUCTION. IX. COD-LIVER OIL VERSUS WHEAT OIL AS SOURCES OF VITAMIN E. Jour. Biol. Chem. 74: 45–53.

(12) ———
1928. DIETARY REQUIREMENTS FOR FERTILITY AND LACTATION. XIII. STORAGE OF FAT-SOLUBLE VITAMINS FOR LACTATION, WITH SOME OBSERVATIONS ON THE COD-LIVER OIL REQUIREMENTS OF NURSING YOUNG. Jour. Biol. Chem. 76: 659–671.

(13) VOEGTLIN, C., and MYERS, C. N.
1918. THE GROWTH-PROMOTING PROPERTIES OF FOODS DERIVED FROM CORN AND WHEAT. Pub. Health Rpts. [U. S.] 33 (22), p. 843–868, illus.

LIBRARY
TNAU, Coimbatore - 3
000001213

THE INFLUENCE OF THE SOIL REACTION ON THE IONIZABLE CONSTITUENTS OF THE TOMATO AS DETERMINED BY ELECTRODIALYSIS[1]

By E. S. Haber[2]

Assistant Chief in Vegetable Crops, Iowa State College

INTRODUCTION

Within recent years electrodialysis as a means of studying certain chemical and physical phenomena has come into use. In studying the effect of soil reaction on the growth of greenhouse plants, especially the tomato, electrodialysis has been used to determine the ratio of acid and basic materials taken up by the plant, depending on the soil reaction (pH value).

A complete review of the literature on electrodialysis up to 1927 is given by Spiegel-Adolph (*11*)[3] and will not be repeated here. Moore, Reeves, and Hixon (*7*) made use of the Mattson (*6*) cell in studying apple tissue affected with Jonathan spot and substantiated Pentzer's (*8*) finding that Jonathan spot is accompanied during storage by a loss of acids in the diseased area.

Bradfield (*2*) by means of the Mattson cell, using KCl, K_2SO_4, and KH_3PO_4, all normal solutions with respect to the potassium content, concluded that in every case the cation was removed more quickly than the anion. The rate of removal of the cation was influenced by the nature of the anion with which it was combined, while the rate of removal of the anions was in the order of $Cl > SO_4 > H_2PO_4$. In every case the cation was removed quantitatively, but the time required was greater, especially in the case of the phosphate ion. Bradfield suggested that the rate of removal of anions would be facilitated by the substitution of a positive membrane for the negative parchment membrane on the anode side.

MATERIALS AND METHODS

New compost soil was placed in the greenhouse bench. The individual plots were separated by boards that extended the entire depth of the bench in order to prevent the soil of one plot from mixing with that of another. The reaction (pH value) of the soil when placed in the benches was 6.5.

Three soil reactions (pH values) were decided upon, one extremely alkaline, pH 8.5–9.0, one neutral or nearly so, pH 6.5–7.0, and one extremely acid, pH 4.0–4.5. These plots were all run in duplicate. To secure the alkaline reaction, the soil was treated with hydrated lime in sufficient quantity so that the pH value was about 9.0 a week after treatment when a fair degree of equilibrium was reached. For the neutral plots the soil was not treated, since it was nearly neutral without treatment. The acid reaction was secured by adding

[1] Received for publication June 26, 1928; issued October, 1928.

[2] The writer wishes to express his thanks to Dr. R. M. Hixon of the Chemistry Department for helpful suggestions and criticisms and for the use of equipment.

[3] Reference is made by number (italic) to "Literature cited," p. 114.

phosphoric acid (H_3PO_4) so that the reaction was 4.0 a week after treatment.

The tomato plants used were of the Bonny Best variety. The seed was sown in a flat, the seedlings pricked off when 1½ inches high and planted in 2-inch pots, later shifted to 4-inch pots, and finally transferred to the experimental plots 10 days after the soil had been treated. The soil used in potting was ordinary compost with a pH value of 6.0–6.5. The crop was benched October 1 and completed its growth February 1. Determinations of the pH values of the soil of the various plots were made at 10-day intervals after the crop was benched. Small amounts of hydrated lime or phosphoric acid were added from time to time to keep the pH within the desired range.

Electrodialysis of the fruit was made with samples picked from the vines and used immediately. Ionizable constituents of the root, stem, and leaf were determined from air-dried material. The Mattson (*6*) cell for electrodialysis as modified by Clark, Humfeld, and Alben (*4*) was used for this purpose. The procedure was similar to that of Moore, Reeves, and Hixon (7) with the exception of size of samples, time intervals, and voltage. In running samples of the root system it was necessary to make a composite sample of two root systems, since 3 gm. of the ground tissue were used and the root system of one plant did not furnish adequate material. In all cases of stems and leaves 3-gm. samples of individual plants were used. The air-dried material was ground in a Wiley mill and passed through a 60-mesh sieve. In the case of the fruits, samples of fresh material composed as nearly as possible of equal sized fruits were made up. Tests were run on both ripe and green fruit. The green fruits were picked just as a faint trace of yellow appeared at the blossom end. By this means it was possible to get composite samples of fruits of about the same degree of maturity. When very green fruits were picked, it was impossible to determine the degree of maturity. Some blossoms were tagged the day they were hand-pollinated, but since all blossoms pollinated on the same day did not mature their fruits anywhere near the same time this gauge of maturity was not reliable. Both ripe and green fruits were run through a food chopper until they were of a creamy consistency. It was impossible to attain this condition with very green fruits, which was another reason for using the fruit just as the first trace of color appeared at the blossom end. Fruits used for analysis when just showing a faint trace of color at the blossom end will be referred to henceforth as "green mature."

In case of the ground tissue of the plant 3 gm. were placed in 300 c. c. of distilled water in the middle compartment and 275 c. c. of water in each of the anode and cathode compartments. The parchment paper used to separate the compartments was dialyzed one hour in distilled water to remove ionizable constituents. The parchment paper was kept in a humid atmosphere before it was used in the cell, for unless this was done the swelling was so great after the water was added as to cause the papers to become limp and flaccid.

Electrodialysis of fruit, leaf, stem, and root tissue rendered none of the pigments soluble, so no discoloration of parchment paper occurred. Consequently, the same parchment paper was used until broken or torn. If the paper was stretched tightly the samples checked much more closely. After the sample had been dialyzed

the compartments were filled with distilled water and the paper was redialyzed to remove any ions remaining from the previous sample: 250 gm. of the green fruit or 275 gm. of the ripe fruit, after being made up to volume of 300 c. c. with distilled water in a 500 c. c. graduate, were placed in the middle compartment, and 275 c. c. of distilled water were used in each of the cathode and anode compartments; 105 to 110 volts of direct current from storage batteries were passed through the cell for all the root, stem, and leaf samples. For the electrodialysis of the fruits 82 volts were used for the first four periods and 108 volts for the others.

All data given are the results of three to five analyses on samples from each plot. These checked within narrow limits when conditions were as nearly alike as possible. In order to obtain comparable samples the platinum electrodes must always occupy the same position in the cell and the parchment membranes must be stretched tight and not allowed to bulge. When these precautions were observed it was relatively easy to obtain checks within 2 to 4 c. c. where the total N/10 titrable acid or base would run as high or higher than 200 c. c. The material which came out on the basic side (anolyte) was titrated with N/10 H_2SO_4 and on the acid side (catholyte) with N/10 NaOH. At the end of the designated time the anolyte and catholyte were drained and the current was shut off. It required about two minutes to drain and refill the anode and cathode compartments, and then the current was turned on again and the time was recorded from the starting and stoppage of the flow of current. This method differed from that of Moore, Reeves, and Hixon (7) in that they left the current flowing while draining and refilling to prevent a return of the ions in the middle compartment. However, closer checks were obtainable where the current was shut off and the same length of time used each period for draining and refilling. Titrations on the acid side (catholyte) were made with N/10 NaOH, but are given in the results as the amount of titratable acid present in the plant tissue. Titratable base determined with N/10 H_2SO_4 are given in terms of N/10 base present in the tissue.

EXPERIMENTAL DATA

Table 1 includes some physical and chemical measurements of ionizable material in the ripe fruits. The voltage given is the initial voltage recorded at the beginning of the period of dialysis. A small drop in voltage occurred where the amperage ran above 1.0, but at no time was the drop more than 5 volts by the end of the period. The dialyzate was drawn off frequently enough to prevent the temperature from going above 30° C. Titratable acid and base are given in cubic centimeters and are figured on a basis of N/10.

Differences in acid and basic constituents due to soil reaction were very small in the ripe fruit. Within 5 hours and 20 minutes all of the basic constituents were removed from fruits taken from plants grown on the alkaline plots and within 4 hours from the neutral and acid plots. There were 4.48 per cent more N/10 base present in the samples from the plots with alkaline reaction than in those from the neutral plots. Conversely, there was 4.87 per cent less N/10 base in the fruits from the acid plots than in fruits from the neutral plot. Fruits from plants grown on the acid soil contained very little more acid than fruits grown on the highly alkaline soil.

TABLE 1.—*Results of electrodialysis of ripe tomato fruit from soils of different pH values*

Time	Current	Soil pH 8.5–9.0			Soil pH 6.5–7.0			Soil pH 4.0–4.5		
		Charge	Base	Acid	Charge	Base	Acid	Charge	Base	Acid
Minutes	*Volts*	*Amperes*	*C. c.*	*C. c.*	*Amperes*	*C. c.*	*C. c.*	*Amperes*	*C. c.*	*C. c.*
10	82	1.30	19.2	10.2	1.50	25.4	12.8	1.40	23.4	10.5
10	82	1.30	20.2	10.2	1.10	20.4	11.7	1.30	22.4	10.6
20	82	3.40	86.6	29.9	3.05	82.4	28.6	3.50	81.4	30.1
20	82	1.15	37.9	17.3	1.05	39.0	17.7	1.10	39.0	18.1
20	108	0.85	21.4	15.8	0.80	15.0	14.6	0.90	15.0	16.5
40	108	1.10	14.2	21.2	0.80	10.8	18.2	0.80	10.8	21.9
40	108	1.00	10.3	18.3	0.40	8.7	15.6	0.20	1.7	18.9
80	108	0.55	3.7	26.1	0.65	3.7	27.0	0.30	1.7	28.1
80	108	0.25	1.1	17.9	0.25	0.0	20.7	0.10	0.0	15.6
80	108	0.15	0.0	14.3	0.10	0.0	17.5	0.10	0.0	18.8
400	....	....	214.6	181.2	....	205.4	184.4	....	195.4	189.1

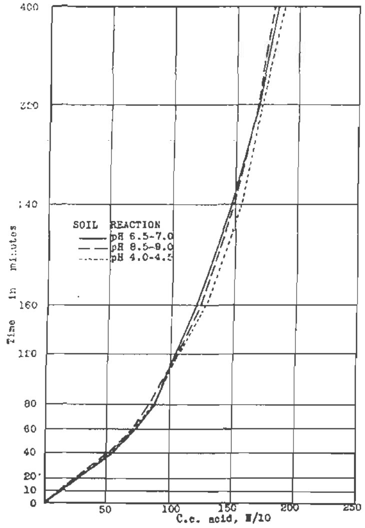

FIG. 1.—The rate of removal of acids by electrodialysis from the ripe fruit of tomato plants grown on soils of different hydrogen-ion concentration

On the other hand, the acid constituents were removed much more slowly than the basic ones. Again, differences due to soil reaction were noted, but they were very small and probably not

significant, since all of the acid constituents were not removed in the time allowed for electrodialysis. The fruit from plants on the alkaline plots contained 1.73 per cent less acid than fruits from the plants on the neutral plots, but fruit from the acid plots contained 2.54 per cent more acid than fruits from the neutral plots.

The acid constituents were removed at a more uniform rate than the basic constituents, as shown in Figures 1 and 2.

Positive correlation between the soil reaction and ionizable acids and bases of the green mature fruit is shown in Figures 3 and 4.

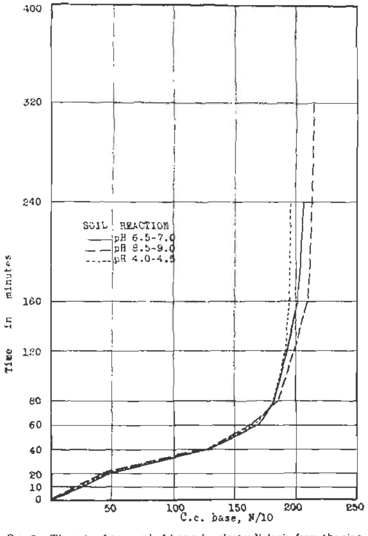

FIG. 2.—The rate of removal of bases by electrodialysis from the ripe fruit of tomato plants grown on soils of different hydrogen-ion concentration

Differences in the ionizable acids and bases in the green mature fruit, depending on the soil reaction, were similar to those found in the ripe fruit. Basic constituents were 2.4 per cent greater in fruits from plants of the alkaline plots and 4.95 per cent less in the fruits from plants of the acid plots as compared with those from the neutral plots. There was 5.01 per cent less acid in fruits from the alkaline plot and 8.37 per cent more acid in the fruits from the acid plots as compared with those from the neutral plots. The percentage differences were greater for acids in the green mature fruit from the

acid and alkaline plots compared to the neutral plots than in the case of the ripe fruits.

Bases were removed from the tissue at a much faster rate than the acids, and although the rate of removal of the acids was much slower it was at a more uniform rate, as shown in Figures 3 and 4. Since the acid constituents were removed much more slowly than the basic ones, electrodialysis of the green mature fruits was carried on for approximately 27 hours to determine if the relative differences of acid or basic constituents, depending on the soil reaction, were changed

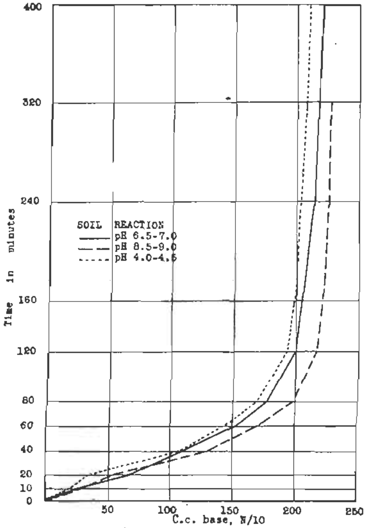

FIG. 3.—The rate of removal of bases by electrodialysis from the green fruit of tomato plants grown on soils of different hydrogen-ion concentration

by electrodialysis over a longer period. The relative differences between the rate of removal of basic and acid constituents as shown in Figures 5 and 6 were practically the same as those given in Figures 3 and 4 for the green mature fruit from the neutral and acid plots when electrodialysis was carried on for the short period.

The bases were removed in 5 hours and 20 minutes from the neutral plots and in 4 hours from the acid plots. This corresponds to the length of time required for the removal of bases, as shown in Figure 3, in which case electrodialysis was carried on for 6 hours and 40

minutes. Although the acids were not completely removed at the end of the long period, there was a difference of 7.34 per cent between the fruits from the neutral and aklaline plots as compared with a difference of 8.37 per cent for the short period. The rates of removal of acids and bases are shown graphically in Figures 5 and 6.

A comparison of the ionizable constituents of the leaves from the three series of soil reactions showed a tendency similar to that of the fruit. The leaves from the plants from the plots with an acid reaction contained more acid and less base than leaves from plants from

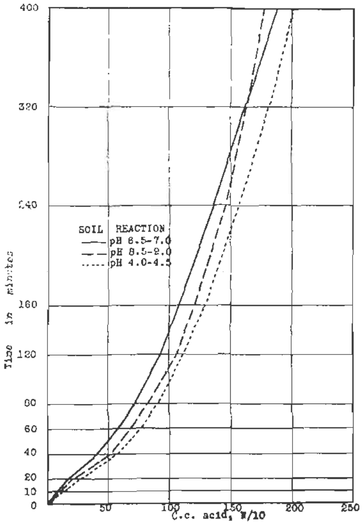

FIG. 4.—The rate of removal of acids by electrodialysis from the green fruit of tomato plants grown on soils of different hydrogen-ion concentration

the neutral plots, while leaves from plants grown on soil with an alkaline reaction contained less acid and more base than leaves from plants grown in neutral soil. The rate of removal of acid and base is shown in Figures 7 and 8.

The pH values of anolyte and catholyte of the leaf material were made by means of the Bailey (*1*) hydrogen electrode. The E. M. F. readings were converted to pH values from the tables given by Schmidt and Hoagland (*10*). Differences in titratable acid of the catholyte between some of the runs from the same tissue were very

great, but the relative change in pH was very slight. The range in pH from the catholyte from all the plots was from 2.33 to 3.07. Changes in pH from the anolyte were greater, showing a range from 11.59 to 8.74. Differences in pH corresponded to the differences in titratable base, but the relative differences in the case of the pH values were not as great.

Data graphically presented in Figures 9 and 10 indicate that the ionizable constituents of the stems were influenced by the soil reaction. Percentage differences in titratable N/10 acid and base, depending

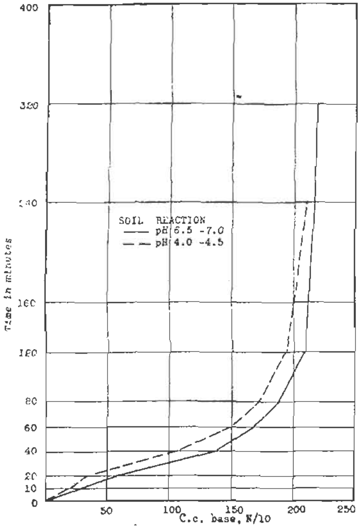

FIG. 5.—The rate of removal of bases by long-continued electrodialysis from the green fruit of tomato plants grown on soils of different hydrogen-ion concentration

on the soil reaction in which the plants were grown, were greater than with leaves and fruit. Differences in pH values of the catholyte were small compared to the amount of titratable acid. Changes in pH of the anolyte showed a greater positive correlation with changes in titratable base.

The greatest differences between amounts of ionizable acid and base, depending on the soil reaction, were found in the root tissue. Root tissue from the alkaline plots contained 78.06 per cent more N/10 base than like tissue from the neutral plots. However, the

tissue from the acid plots contained only 15.10 per cent less base. The root tissue contained 60.14 per cent more N/10 acid when the plants were grown in an acid soil than when they were grown in a neutral soil. Changes in pH of the catholyte were small; however, differences in the titratable acid were great. Changes in pH of the anolyte corresponded to changes in titratable base to a greater degree than with any of the other tissues dialyzed. Figures 11 and 12 indicate the rate at which the N/10 acid and base were removed.

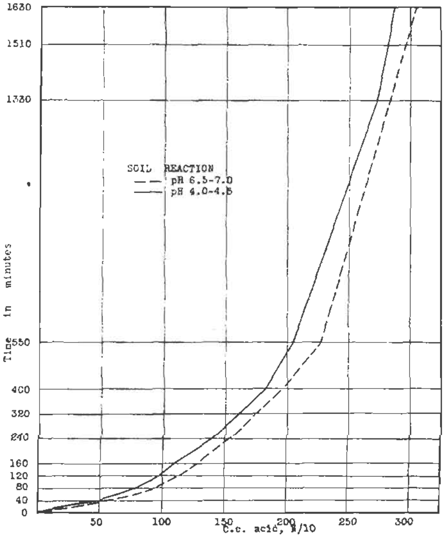

FIG. 8.—The rate of removal of acids by long-continued electrodialysis from the green fruit of tomato plants grown on soils of different hydrogen-ion concentration

Table 2 is a brief summary of the more important findings. Differences in total titratable N/10 acid and base only are included. Differences in cubic centimeters and percentages of the amount of acid and base contained in the respective tissues are presented. Findings with respect to the amount of ionizable constituents in tissues from plants grown in the neutral plots were taken as a basis of comparison.

TABLE 2.—*Difference in titratable acid and base from various parts of the tomato plant*

Sample	Soil reaction	N/10 base	Difference		N/10 acid	Difference	
		Cubic centimeters	*Cubic centimeters*	*Per cent*	*Cubic centimeters*	*Cubic centimeters*	*Per cent*
Ripe fruit	pH 8.5–9.0	214.6	+9.2	+4.48	181.2	−3.2	−1.73
	pH 6.5–7.0	205.4			184.4		
	pH 4.0–4.5	195.4	−10.0	−4.87	189.1	+4.7	+2.54
Green mature fruit	pH 8.5–9.0	225.5	+5.3	+2.40	176.1	−9.4	−5.01
	pH 6.5–7.0	220.2			187.5		
	pH 4.0–4.5	209.3	−10.9	−4.95	203.2	+15.7	+8.37
Leaves	pH 8.5–9.0	192.6	+10.7	+5.88	104.0	−5.9	−5.46
	pH 6.5–7.0	181.9			109.8		
	pH 4.0–4.5	175.6	−6.3	−3.46	121.1	+21.2	+19.29
Stems	pH 8.5–9.0	126.9	+23.2	+22.37	82.5	−10.0	−10.81
	pH 6.5–7.0	103.7			92.5		
	pH 4.0–4.5	91.5	−12.2	−11.76	112.0	+19.5	+21.08
Roots	pH 8.5–9.0	103.1	+45.2	+78.06	44.7	−10.7	−19.56
	pH 6.5–7.0	57.9			54.7		
	pH 4.0–4.5	49.1	−8.8	−15.19	87.6	+32.9	+60.14

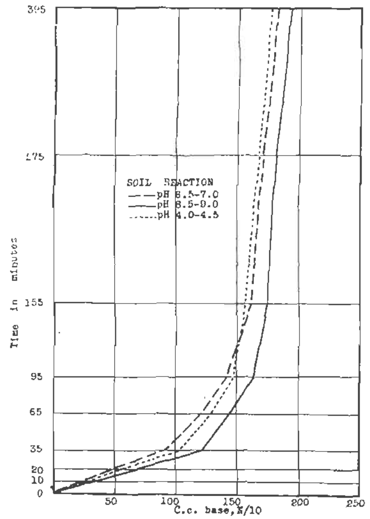

FIG. 7.—The rate of removal of bases by electrodialysis from the leaves of tomato plants grown on soils of different hydrogen-ion concentration

DISCUSSION

Three grams of air-dried tissue was used in all cases where roots, stems, and leaves were dialyzed. Fresh material was used with the fruit, 250 gm. of the "green mature" and 275 gm. of the ripe fruit.

According to Wehmer (*13, p. 678*), the ripe tomato fruit contains 92 to 94 per cent of water. Therefore the fruit samples contained 7 to 9 gm. on a dry-weight basis. This was two to three times as much as the root, stem, and leaf samples. Consequently, the roots and fruits contained the least amount of ionizable material and the leaves contained the greatest amount, as measured in terms of N/10 titratable acid and base.

The various samples of the plant tissue used were as large as practicable in order to obtain a large amount of acid and basic ma-

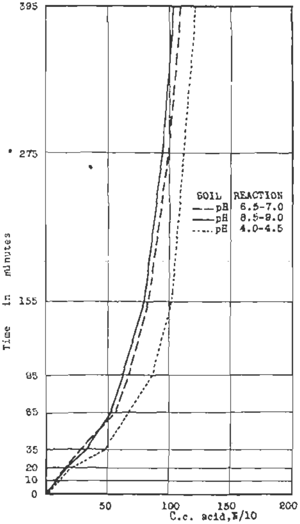

FIG. 8.—The rate of removal of acids by electrodialysis from the leaves of tomato plants grown on soils of different hydrogen-ion concentration

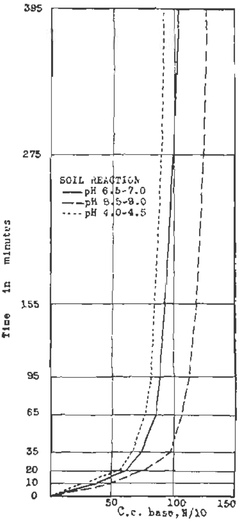

FIG. 9.—The rate of removal of bases by electrodialysis from the stems of tomato plants grown on soils of different hydrogen-ion concentration

terial. Since the titrations were with N/10 H_2SO_4 and N/10 NaOH, the larger the total amount of acid or base required to neutralize the dialysate the smaller the error. The size of the sample was governed by the amperage in a given length of time. It was not deemed advisable to allow the amperage to go above 4 for more than one or two minutes, and it was preferable to hold it below 2, since with high amperage high temperatures resulted. It may be noted that the amperage corresponded to the amount of acid and base removed, especially in the early stages of dialysis. The greater the total of

ionizable constituents present in the dialysate, the greater the amperage.

The greatest percentage differences of the acid and basic constituents, depending on the acidity or alkalinity of the soil, were found in the root systems. These differences decreased in the order of roots, stems, leaves, green mature fruit, and ripe fruit.

It is not surprising to find the greatest differences in acid and basic materials in the root systems of plants grown in acid and basic soils. Since the alkaline soil was treated with hydrated lime, one would

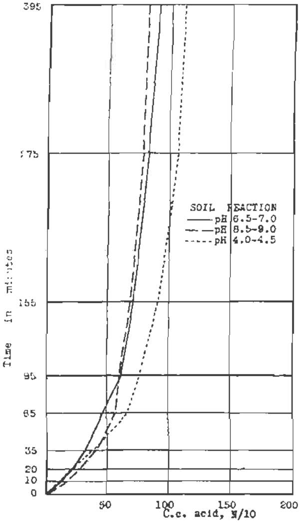

FIG. 10.—The rate of removal of acids by electrodialysis from the stems of tomato plants grown no soils of different hydrogen-ion concentration

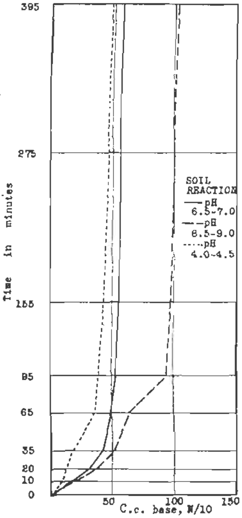

FIG. 11.—The rate of removal of bases by electrodialysis from the roots of tomato plants grown on soils of different hydrogen-ion concentration

expect to find a greater amount of calcium salts present in the plants. The acid soil having been treated with phosphoric acid would contain more acid material. Hartwell (*5*) found the precentage of phosphorus in turnips to be positively correlated with the amount of available phosphorus in the soil. Truog (*12*) pointed out that the pH value of the tissue or extract of a number of agricultural plants could be raised by the addition of lime to acid soils in which the plants were growing. This would indicate the intake of a greater amount or proportion of alkaline material. The findings of Reed and Haas

(*9*) were contrary to this, as they reported no differences in pH values of the sap expressed from walnut seedlings regardless of the reaction of the solution in which they were grown.

As stated previously, the differences between titratable acid and base, depending on the acidity or alkalinity of the soil, became less in the order of root, stems, leaves, and fruit. Burgess and Pember (*3*) found the highest percentages of aluminum in the roots, considerable in the leaves, a little in the stems, and none in the grain

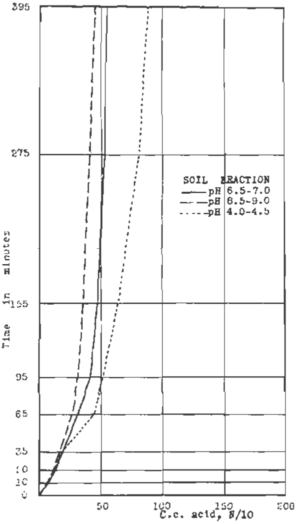

FIG. 12.—The rate of removal of acids by electrodialysis from the roots of tomato plants grown on soils of different hydrogen-ion concentration

of barley. It may be logical to suggest from their results and from those reported in these experiments that there is an equalization of base and acid materials by the time the ionizable material reaches the fruit.

The pH values of anolyte and catholyte were taken for roots, stems, and leaves, but the differences were small, especially where the amount of titratable acid and base was large. This might well be expected where the solutions were well buffered.

SUMMARY

More acid materials as determined by electrodialysis were found in plants grown on acid soil and more basic materials in plants grown on alkaline soil. The percentage differences were in the order root, stem, leaf, and fruit.

The leaves contained the greatest amount of ionizable materials; roots and fruit apparently contained the least.

LITERATURE CITED

(1) Bailey, C. H.
1920. A SIMPLE HYDROGEN ELECTRODE. Jour. Amer. Chem. Soc. 42: 45–48, illus.

(2) Bradfield, R.
1928. AN INEXPENSIVE CELL FOR THE PURIFICATION OF COLLOIDS BY ELECTRODIALYSIS. Indus. and Engin. Chem. 20: 79–80, illus.

(3) Burgess, P. S., and Pember, F. R.
1923. "ACTIVE" ALUMINUM AS A FACTOR DETRIMENTAL TO CROP PRODUCTION IN MANY ACID SOILS. R. I. Agr. Expt. Sta. Bul. 194, 40 p., illus.

(4) Clark, N. A., Humfeld, H., and Alben, A. O.
1927. ELECTRODIALYSIS OF SOILS AND THE MATTSON CELL. Soil Sci. 24: 291–295, illus.

(5) Hartwell, B. L.
1913. THE PERCENTAGE OF TOTAL PHOSPHORUS IN FLAT TURNIPS AS INFLUENCED BY THE AMOUNT AVAILABLE IN SOILS. R. I. Agr. Expt. Sta. Bul. 154, p. [121]–148.

(6) Mattson, S.
1926. ELECTRODIALYSIS OF THE COLLOIDAL SOIL MATERIAL AND THE EXCHANGEABLE BASES. Jour. Agr. Research 33: 553–567, illus.

(7) Moore, J. C., Reeves, R. G., and Hixon, R. M.
1927. ELECTRODIALYSIS AS A MEANS OF STUDYING BIOCHEMICAL DIFFERENCES IN ABNORMAL APPLE TISSUE. Plant Physiol. 2: 313–324, illus.

(8) Pentzer, W. T.
[1926]. COLOR PIGMENT IN RELATION TO THE DEVELOPMENT OF JONATHAN-SPOT. Amer. Soc. Hort. Sci. Proc. (1925) 22: 66–69.

(9) Reed, H. S., and Haas, A. R. C.
1924. NUTRIENT AND TOXIC EFFECTS OF CERTAIN IONS ON CITRUS AND WALNUT TREES WITH ESPECIAL REFERENCE TO THE CONCENTRATION AND P_H OF THE MEDIUM. Calif. Agr. Expt. Sta. Tech. Paper 17, 75 p., illus.

(10) Schmidt, C. L. A., and Hoagland, D. R.
1919. TABLE OF PH, H^+ AND OH^- VALUES CORRESPONDING TO ELECTROMOTIVE FORCES DETERMINED IN HYDROGEN ELECTRODE MEASUREMENTS. Calif. Univ. Pubs., Physiol. 5: 23–69.

(11) Spiegel-Adolf, M.
1927. ELEKTRODIALYSE. *In* Abderhalden, E., Handbuch der biologischen Arbeitsmethoden. Lfg. 248: [595]-628, illus. (Abt. 3, Teil B, Heft 4.)

(12) Truog, E.
1918. SOIL ACIDITY: I. ITS RELATION TO THE GROWTH OF PLANTS. Soil Sci. 5: 169–195.

(13) Wehmer, C.
1911. DIE PFLANZENSTOFFE. 678 p. Jena, Gustav Fischer.

RAPID GROWTH OF CHICKS ON RATIONS OF NATURAL FOODSTUFFS [1]

By Albert G. Hogan, Charles L. Shrewsbury, and Harry L. Kempster,
Missouri Agricultural Experiment Station

INTRODUCTION

During the course of studies on the nutritional requirements of the chick, diets of natural foodstuffs were frequently used as controls for the synthetic rations. Surprising variations were noted, however, in the rate at which different individuals grew, even on rations of commercial materials, which were presumably adequate in every respect. It finally became apparent that the variability was due to unsuspected deficiencies in the rations employed, and an attempt was made to formulate a more satisfactory diet. This effort [2] was successful beyond expectation, for not only was the variability decreased, but the rate of growth was more rapid than any recorded, as far as the writers are aware, for the particular breed of chicks used in these experiments. However, these earlier successes were without immediate interest except for experimental purposes, because of the high price of the ration. An attempt was therefore made to prepare from more readily available constituents a ration that would be equally effective in supporting growth.

EXPERIMENTAL PROCEDURE AND RESULTS

During the last two years a large number of rations were tested in an effort to develop one giving some promise of practical value. However, only four of these are described herein and, as is evident from Table 1, all of them are very similar in composition, although corn predominates in two of the rations and wheat in the other two.

Table 1.—*Composition of experimental rations*

Components of ration	Percentage composition of ration—			
	No. 564	No. 803	No. 806	No. 810
	Per cent	*Per cent*	*Per cent*	*Per cent*
Yellow corn	65.5		65.5	
Wheat		65.5		65.5
Liver meal	15.0	15.0		
Tankage			15.0	15.0
Dried buttermilk	10.0	10.0	10.0	10.0
Alfalfa meal	5.0	5.0	5.0	5.0
Cod-liver oil	2.0	2.0	2.0	2.0
Sodium chloride	1.0	1.0	1.0	1.0
Calcium carbonate	1.5	1.5	1.5	1.5

[1] Received for publication July 5, 1928; issued October, 1928.
[2] Hogan, A. G., Hunter, J. E., and Kempster, H. L. acceleration of growth rates by dietary modifications. Jour. Biol. Chem. 77: 431–436, illus. 1928.

Journal of Agricultural Research,
Washington, D. C.

Vol. 37, No. 2
July 15, 1928
Key No. Mo.-10

Only White Leghorn chicks have been used, and all were reared under strictly laboratory conditions, as described in an earlier publication.[3] The solids of the ration were intimately mixed, in a finely divided condition, and the cod-liver oil was then added. Fresh mixtures were made up each week, or oftener. The all-mash system of feeding was followed exclusively, chiefly for convenience. No attempt was made to determine whether or not it is superior to other methods that are more commonly used.

The first ration used, No. 564, proved fairly satisfactory, but the chicks' rate of growth was considerably below the optimum. A more successful ration, described in an earlier paper,[4] contained dried whole milk, and it seemed to the writers that the inclusion of milk would probably make ration 564 equally satisfactory. The use of whole

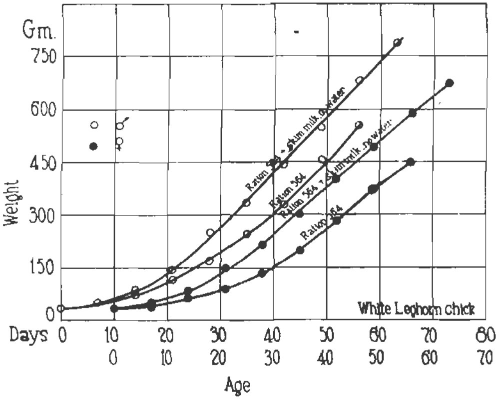

FIG. 1.—Growth of chicks as affected by skim milk in the ration. All chicks were given the same basal ration, No. 564. Those that received skim milk in addition grew more rapidly than those that received water

milk is impractical, but skim milk offered some promise as a substitute. Water, therefore, was withdrawn entirely from some groups of chicks and skim milk was offered instead.

In all, three groups of chicks, at different times, have been reared on ration 564, and they have all grown at about the same rate. Four groups have received skim milk in addition to ration 564, and they too have grown very uniformly. In Figure 1 are presented the growth curves of groups on these rations, kept under observation at the same time, and therefore strictly comparable.

A number of modifications of ration 564 have been tried that seem worthy of mention, though detailed description will not be attempted.

[3] HOGAN, A. G., GUERRANT, A. B., and KEMPSTER, H. L. CONCERNING THE ADEQUACY OF SYNTHETIC DIETS FOR THE GROWTH OF THE CHICKS. Jour. Biol. Chem. 64: 113-124, illus. 1925.

[4] HOGAN, A. G., HUNTER, J. E., and KEMPSTER, H. L. Op. cit.

At three different times ration 672, a mixture of 90 parts of ration 564 and 10 parts of dried yeast, was used, with a considerable degree of success. The mixture supported growth at practically the same rate as ration 564 and skim milk. Growth was a little more rapid still when skim milk was fed along with ration 672, though the difference was not great.

The modifications of ration 564 that were of most interest involved the substitution of tankage for liver meal and of wheat for yellow corn. The combination of corn and tankage has been definitely inferior to any of the others, and as a rule rations containing corn are slightly inferior to those containing wheat, but the inferiority is slight except when tankage is used as a protein concentrate. It was

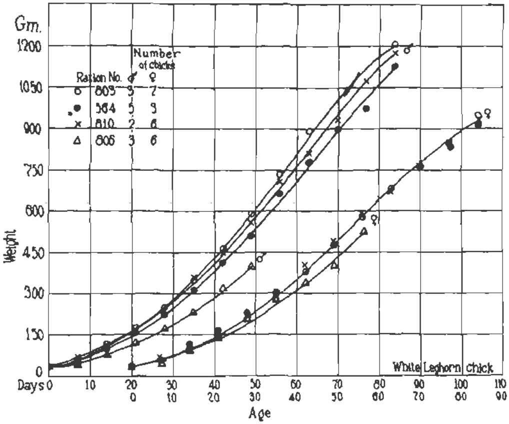

FIG. 2.—Growth of chicks on various rations. The composition of the rations is given in Table 1. Of the combinations listed, corn and tankage is least effective. Rations containing wheat are superior to those containing corn

surprising to note that the wheat-tankage combination was practically as effective as any other used. A comparison of growth rates on the four combinations tried is presented in Figure 2.

In order to present a more complete view of the growth of these chicks a graph (fig. 3) is included which shows the growth of a group that was kept under observation until it reached maturity. For purposes of comparison an age-weight curve of chicks which were grown by standard methods is also included. So far as the writers are aware these controls made more rapid growth[5] than any others of the same breed reported in the literature.

[5] BUCKNER, G. D., WILKINS, R. H., and KASTLE, J. H. THE NORMAL GROWTH OF WHITE LEGHORN CHICKENS. Amer. Jour. Physiol. 47: 393-396, illus. 1918.

An inspection of Figure 3 shows that chicks on ration 803 supplemented with skim milk grew more rapidly and attained a mature weight at an earlier age than the controls. Whether this difference is due to the ration or to genetic factors can not be decided with the evidence available. It may be that the strain of chicks used is smaller and attains maturity more quickly.

In connection with the rate of growth, the initial weights of the chicks may be significant. The average weight at hatching of the males described herein was 31 gm., and the average weight of the females was 33 gm. In contrast with these, the average weight of the males used as controls was 42 gm. and the average weight of the

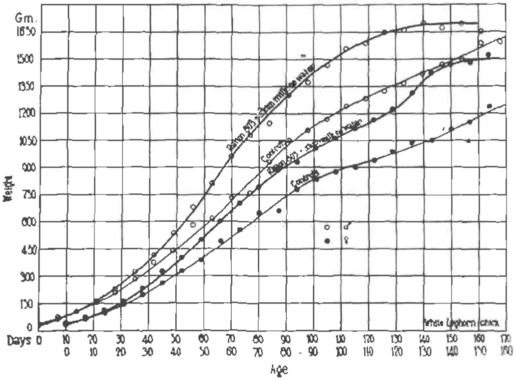

FIG. 3.—Growth of chicks to maturity on a wheat ration supplemented with skim milk. These are age-weight curves of one of the few groups of chicks that were permitted to attain mature weights. The chicks used as controls were, so far as is known, the most rapidly growing yet described

females was practically 41 gm. The chicks with the heavier initial weights usually grow most rapidly.

One difficulty, the incidence of leg weakness, encountered in rearing chicks by the method used in these experiments requires a brief description. In all 146 chicks were reared on the rations described and on various modifications, and of these 16, or practically 11 per cent, developed a form of leg weakness characterized chiefly by gross deformities. This abnormality can not be explained from what is now known of avian physiology. Data reserved for future publication show that the bones are normal in composition and that the percentages of calcium and of inorganic phosphorus in the blood are normal. It seems certain that the condition is not rickets, and there is no definite indication of polyneuritis. Sporadic attempts have been made to prevent this abnormality by using various mineral mixtures, but to no avail. A few chicks were growing poorly when the symptoms were noted, though deaths were rare. In some instances the

most rapidly growing chicks had badly deformed legs. Experiments are now under way to decide whether crowding and close confinement may be responsible. Typical illustrations of this type of leg weakness appear in Figure 4, A, B.

Before leaving the question of leg weakness entirely, an instance should be described that merits recording, though the abnormality

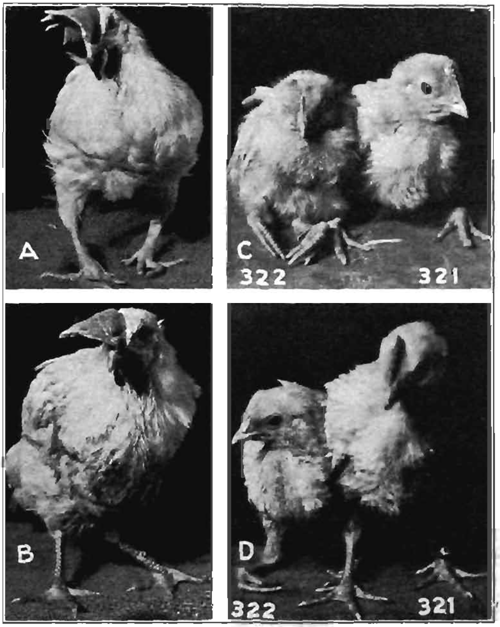

FIG. 4.—A, B.—These chicks illustrate the type of leg weakness encountered so frequently in the experiments herein reported. The *one* shown in B is most typical. Treatment with yeast, in small quantities at least, is ineffective. C.—Two chicks which developed leg weakness at 25 days of age and were unable to stand. D.—The chicks shown in C, but greatly improved by treatment with yeast. They ultimately recovered. When this photograph was taken they were 27 days old

may not be identical with the one described in the preceding paragraph. In an earlier paper [6] ration No. 400 was mentioned as being used with variable success. This ration contains whole wheat, 65.5; whole milk powder, 9.7; commercial casein, 14.5; alfalfa meal, 2.9; milk fat, 4.9; sodium chloride, 1.0; and calcium carbonate, 1.5.

One morning, 25 days after a group of chicks had been placed on this ration, two of them were found in an almost helpless condition. One was given considerable quantities of yeast and appeared almost normal two days later. The other was given a small quantity of yeast and cod-liver oil in addition and made less improvement by the second day. Larger quantities of yeast were then given, and on the fourth day both were normal in appearance. One had a relapse on the eithteenth day after the first attack, but treatment with yeast over a seven-day period seemed to bring about complete recovery.

It appears improbable that the response of the two chicks just described to ration 400 can be adequately explained on the basis of knowledge at present available. It seems certain, however, that the diet is only partially adequate, and that the inadequacy can be remedied by feeding yeast. Presumably the deficient substance is intimately related to vitamin B. Figure 4, C, D, illustrates the appearance of these chicks at the time of collapse and after treatment with yeast.

The mortalities are of considerable importance, so a report of these losses is included herein. In addition to the 146 chicks that were reared, there were 2 that died in their sixth week, another was killed because it had become badly hampered by deformities of the legs; and another was killed by accident. Besides these 4, there were 30 others that died or were killed within the first two weeks. Practically all of these were diagnosed as suffering from diarrhea, but how many cases were of the bacillary type can not be said. Most of these chicks were purchased from a commercial hatchery, so it is possible that they were infected when brought to the laboratory. The mortality rate would, of course, be more significant if it were known how many chicks were infected at the beginning of the observations.

The records of food consumption are also of interest, though chicks are wasteful feeders, and accuracy is not easily attained. One can only be sure that not more than a certain amount of food was consumed. The records were obtained on groups of chicks, and each group contained individuals of both sexes. The records are summarized in Table 2.

It is evident that if comparable stages of the growing periods are considered, chicks compare very favorably with other animals in the economy of growth. During the first two weeks less than 2 pounds of feed were required to produce a gain of 1 pound. At the end of the sixth week the weight of the males was practically 1 pound, and the food consumption per pound gain had not yet reached 3 pounds. Following the sixth week the cost of gains continued to increase until by the end of the twelfth week 6 or 7 pounds of food were required to produce a gain of 1 pound. A rough calculation shows that when a chick weighs 1 pound it has consumed about 3 pounds of food. About 8 pounds are required to being a chick to a weight of 2 pounds, and 13.5 pounds of food are necessary to bring it to a weight of 3 pounds.

The commercial value of the rations herein described may be regarded as promising, but tests under practical conditions have not yet been completed. If it should seem profitable to use extensively rations of the type described in this paper, further study should be given to their composition, and to the methods of using them. It is entirely possible that the formulas could be so changed as to make them less expensive without decreasing their usefulness. Such changes unquestionably could be made in the later stages of the growing period.

TABLE 2.—*Gain in weight and food consumption of growing chicks on different rations*

Age of chicks	Ration No. 803					Ration No. 801				
	Gain in weight per week	Weight of dry food	Weight of skim milk	Total solids consumed [a]	Solids consumed per gram of gain in weight	Gain in weight per week	Weight of dry food	Weight of skim milk	Total solids consumed [a]	Solids consumed per gram of gain in weight
Weeks	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	242	580	1,390	719	3.0	251	290	1,400	430	1.7
2	461	590	2,325	823	1.8	459	620	2,325	853	1.9
3	493	1,290	3,000	1,590	3.2	525	930	3,000	1,230	2.3
4	686	1,120	4,100	1,530	2.2	444	1,110	4,000	1,510	3.4
5	785	2,250	6,800	2,930	3.7	1,020	710	5,400	1,250	1.2
6	1,080	2,180	8,400	3,020	2.8	895	1,810	7,800	2,590	2.9
7	1,035	2,980	10,000	3,980	3.8	910	3,300	8,000	4,100	4.5
8	1,165	5,570	10,800	6,650	5.7	780	3,570	9,800	4,550	5.9
9	1,190	5,260	14,200	6,680	5.6	1,090	5,610	13,800	6,990	6.3
10	780	4,290	14,200	5,710	7.3	920	3,740	13,400	5,080	5.5
11	905	4,240	14,000	5,640	6.2	700	3,700	14,000	5,100	7.3
12	1,070	4,410	14,600	5,870	5.5	1,150	5,440	14,600	6,800	6.0
Total	9,900	34,760	103,815	45,142	4.6	9,144	30,730	97,525	40,483	4.4

Age of chicks	Ration No. 810					Ration No. 806				
	Gain in weight per week	Weight of dry food	Weight of skim milk	Total solids consumed [a]	Solids consumed per gram of gain in weight	Gain in weight per week	Weight of dry food	Weight of skim milk	Total solids consumed [a]	Solids consumed per gram of gain in weight
Weeks	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	204	190	1,425	333	1.6	164	150	1,500	290	1.8
2	401	590	2,325	793	2.0	325	540	2,200	760	2.3
3	475	690	3,000	990	2.1	406	550	2,900	840	2.1
4	304	960	3,900	1,350	4.4	524	900	3,600	1,260	2.4
5	705	1,800	5,200	2,320	3.3	600	1,890	5,400	2,430	4.1
6	870	1,860	7,800	2,640	3.0	675	2,120	7,000	2,820	4.2
7	710	1,760	8,600	2,620	3.7	610	1,760	7,800	2,540	4.2
8	920	2,500	9,300	3,430	3.7					
9	675	4,920	14,200	6,340	9.4					
10	825	4,730	12,600	5,900	7.3					
11	695	3,750	14,000	5,150	7.4					
12	810	3,790	14,000	5,190	6.4					
Total	7,594	27,510	96,360	37,146	4.9	3,306	7,910	30,300	10,940	3.3

[a] This value is obtained by assuming that the skim milk contains 10 per cent of solids, and adding this calculated value to the weight of dry food consumed. No correction is made for the moisture content of this dry food.

SUMMARY

Rations have been prepared which permit chicks, under laboratory conditions, to grow at an unusually rapid rate. The constituents of these rations are natural foodstuffs, or readily available commercial preparations.

Approximately 10 per cent of the chicks reared in restricted quarters developed leg weakness. This abnormality has not been associated with any known dietary deficiency.

The quantity of food required to produce gains in weight in chickens was similar to that required by other animals at comparable stages of growth.

PHOSPHORUS DISTRIBUTION IN GRAINS [1]

By J. E. Webster [2]

Department of Agricultural Chemistry Research, Oklahoma Agricultural Experiment Station

INTRODUCTION

In past years considerable attention has been given to the subject of nitrogen and carbohydrate fractionation of plant materials, and a vast sum of data has accumulated. Phosphorus and its compounds in plants have, however, been little studied. Recent advances in methods of study, especially of the phospholipin fraction, have directed attention to the phosphorus compounds in plants, and the writer has undertaken to make a rather complete study of changes occurring both in seeds and in green plants. As a preliminary step toward this end, a study of the phosphorus fractions in a group of seeds has been made and the results are reported in this article. Previous workers have made studies on certain of these fractions in grains, but none seems to have made a comprehensive fractionation.

REVIEW OF LITERATURE

Averill and King (*2*)[3] have determined the phytin content of several foodstuffs and give a discussion of the method and modifications they used. Their results are expressed as phytin. Rather (*8*) also has worked on the Heubner and Stadler method for phytin estimation and his procedure is the one followed in the present work. He reports some results for total and acid-soluble phosphorus as well as phytin, in plant materials. Collison (*3*) reports on the inorganic phosphorus content of several grains and also gives an improved method for its estimation, which method is the one used in this work.

The solubility and distribution of phosphorus compounds in seeds has also been studied by Koehler (*7*). His extensive work deals mainly with total, inorganic, and organic compounds in a few seeds, and a large part of his work is on methods.

Guerrant (*5*) has analyzed seeds of various kinds for their phospholipin content and discusses the relation of this fraction to various other constituents such as ash, fat, and protein. He finds no significant relationship. Other workers have made various phosphorus determinations on plant material, but the foregoing summarizes the more important recent publications.

EXPERIMENTAL METHODS AND DATA

The seeds used in the work here reported were all of the 1927 crop and were stored in half-gallon jars with p-dichlorobenzene added as a disinfectant. Openings, screened with fine copper gauze, were

[1] Received for publication May 31, 1928; issued October, 1928. Published with the permission of the Director of the Oklahoma Experiment Station.

[2] The writer wishes to express his thanks to the members of the Agronomy Department for the seeds which they furnished and to Dr. Heller for his aid and suggestions.

[3] Reference is made by number (italic) to "Literature cited," p. 125.

made in the caps to permit gas exchange. The seeds, before analysis, were so ground as to pass the finest mesh screen of the Wiley mill.

Two-gram samples of the finely ground seeds were dried overnight at 105° C. and weighed for moisture determination, after which the samples were ashed in a muffle furnace and weighed to secure the ash.

The fat percentage was obtained by the usual ether-extraction method run on dried samples.

Germination was made early in the fall and was intended to give some idea of viability, since it was thought that changes in viability might occasion certain phosphorus changes.

The determination of total phosphorus was made according to the official volumetric method (*1*) on samples digested, using H_2SO_4, K_2SO_4, and $CuSO_4$, as was done by Jones and Perkins (*6*).

Phospholipin phosphorus was determined by the microcolorometric method of Guerrant (*4*), modified only to the extent of using 50 c. c. of the alcohol-ether mixture per gram of material in place of the 25 c. c. which he recommends.

The determination of phytin phosphorus was carried out by the iron-titrametric method suggested by Rather (*8*).

Collison's improved method as given in the Journal of Biological Chemistry (*3*) was used without change for the determination of inorganic phosphorus.

The values of other phosphorus were secured by subtracting the sum of the various fractions from the total phosphorus figure. It necessarily follows that this figure is not of great value since it contains the errors of the other figures.

The figures in Table 1 are calculated to a dry-weight basis. In every case a sufficient number of determinations was made to secure closely checking and consistent figures, and wherever possible these were compared with published results in other articles.

TABLE 1.—*Analysis and percentage germination of seeds as related to the distribution of phosphorus*

Seeds analyzed	Percentage germination	Percentage of water	Analysis expressed in percentage of dry weight						
			Fat	Ash	Total phosphorus	Phytin phosphorus	Lipoid phosphorus	Inorganic phosphorus	Other phosphorus
Mung bean	100	8.94	0.77	3.77	0.5305	0.3418	0.0404	0.0239	0.1244
Soy bean	100	6.65	16.90	5.54	.5469	([a])	.0966	.0178	--------
Cowpea	95	8.84	1.73	3.28	.4736	.1438	.0459	.0262	.2557
Wheat	80	8.68	2.33	1.77	.4274	.3033	.0263	.0210	.0748
Barley	72	8.08	2.39	2.96	.3937	.1794	.0220	.0222	.1701
Common kafir	82	11.04	3.23	1.82	.3704	.2900	.0206	.0157	.0541
Yellow corn	98	8.48	5.25	1.50	.3468	.2965	.0352	.0124	.0127
Oats	98	8.23	4.94	3.99	.3453	.1905	.0290	.0149	.1109
White corn	94	5.79	5.85	1.48	.3194	.2443	.0485	.0156	.0110
Darso	64	10.65	3.57	1.49	.3117	.2714	.0227	.0158	.0018
Rye	75	8.79	1.99	1.87	.2947	.2059	.0325	.0197	.0366

[a] The solutions were so colored that no satisfactory results could be secured.

DISCUSSION

In discussing the data presented in Table 1, only one salient fact stands out: There seems to be no relation between the total phosphorus content of the seeds and that of any of the fractions, nor is

there any comparable variation found among the different fractions. It was thought that perhaps there would be some relation shown between the fat and phospholipin content, but such is not the case. While it is true that low germination appears to be associated with low phospholipin content, this is probably accidental. It was also thought that there might be some relation between the ash content and the inorganic phosphorus, but no constant relationship is apparent. Phytin phosphorus is, in nearly every case, the most important fraction; in only two instances does it constitute less than 50 per cent of the total and in Darso it represents 87 per cent. The inorganic phosphorus represents only a very small percentage of the total, as does also the phospholipin fraction in most instances.

LITERATURE CITED

(1) Association of Official Agricultural Chemists.
1925. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. COMPILED BY THE COMMITTEE ON EDITING METHODS OF ANALYSIS. REVISED TO JULY 1, 1924. Ed. 2, 535 p., illus. Washington, D. C.

(2) Averill, H. P., and King, C. G.
1926. THE PHYTIN CONTENT OF FOODSTUFFS. Jour. Amer. Chem. Soc. 48: 724–728.

(3) Collison, R. C.
1912. INORGANIC PHOSPHORUS IN PLANT SUBSTANCES. AN IMPROVED METHOD OF ESTIMATION. Jour. Biol. Chem. 12: 65–72.

(4) Guerrant, N. B.
1926. A MICRO-COLORIMETRIC METHOD FOR THE ESTIMATION OF PHOSPHOLIPINS IN SEEDS. Jour. Amer. Chem. Soc. 48: 2185–2190.

(5) ———
1927. SOME RELATIONS OF THE PHOSPHOLIPINS IN SEEDS TO OTHER CONSTITUENTS. Jour. Agr. Research 35: 1001–1019.

(6) Jones, W., and Perkins, M. E.
1923. THE GRAVIMETRIC DETERMINATION OF ORGANIC PHOSPHORUS. Jour. Biol. Chem. 55: 343–351.

(7) Koehler, S.
1927. SUR LES COMPOSÉS PHOSPHORÉS DES PLANTES I. LA SOLUBILITÉ ET LA RÉPARTITION DES COMPOSÉS PHOSPHORÉS CONTENUS DANS LES SEMENCES. Acad. Polon. Sci. Lettres, Cl. Sci. Math. et Nat. Bul. Internatl. (B, 1926) 8: 707–848, illus. (Reprint.)

(8) Rather, J. B.
1917. THE DETERMINATION OF PHYTIN PHOSPHORUS IN PLANT PRODUCTS. Ark. Agr. Expt. Sta. Bul. 135, 15 p.